INTRODUCTION TO BIOLOGY

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INTRODUCTION TO BIOLOGY

AN ELEMENTARY TEXTBOOK AND LABORATORY GUIDE

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PREFACE

THIS elementary textbook and laboratory guide is intended for use in the first or second year of the high school course. The authors' "Applied Biology" is better adapted to students more advanced than the second year of high school, and even for the second year in some schools in which there is need of more supplementary reading than this "Introduction" provides.

This book is not a combined textbook of botany and zoölogy, for it makes no attempt at a systematic presentation of either of these sciences. It is simply what its title suggests; an *introduction* to biological facts and ideas. These have been selected with reference to their direct bearing on the daily life of intelligent citizens. In short, this is an introduction to biology considered as science applicable to human life especially in economic or practical and hygienic lines, with limited attention to facts and ideas whose applications are æsthetic and intellectual (*e.g.* evolution).

The authors have aimed to make this book an introduction to the usual courses in botany and zoölogy. Necessarily, some of the materials for study are the same as those used in such courses; but, on the whole, this book ought to prepare for, rather than wastefully to anticipate, strong courses of botany or zoölogy which in many high schools will probably be offered as electives in later years.

While recognizing that at present a large number of students in high schools are quite ignorant of the most elementary nature-study such as many schools teach well even in the

primary grades, it has seemed best to avoid giving prominence to nature-study in this high-school book. There has long been a tendency towards making a large part of courses of biology in the first year of some high schools little more than nature-study suitable for fourth to seventh grades. The authors have failed to find high schools in which such nature-study is made difficult or dignified enough to hold the attention and the respect of the students as do the other sciences; and this has led to the opinion that a very limited amount of nature-study for the sake of general acquaintance with the common organisms and their most striking habits should supplement, rather than form an integral part, of high-school courses of biology. The authors believe that, for high-school students, a general knowledge of the structure, and especially of the functions, of a few well-selected animals and plants viewed from the standpoint of applied science is to the average citizen more useful than nature-study information (especially names, habits, and other interesting facts) concerning dozens of common organisms. For instance, an understanding of the respiratory machinery and its workings in a seed-plant, an insect, a fish, an earthworm, and a lung-breathing animal is worth more to the average intelligent person than knowing the names of numerous common insects, trees, and birds.

The appendix contains a table for ready reference to sections of the authors' "Applied Biology" and its accompanying "Teachers' Manual of Biology." In these books will be found many supplemental facts and references that will be useful to teachers of classes that use this "Introduction."

As in the "Applied Biology," the authors have thought it best to make extensive use of the standard illustrations which, although more or less familiar to well-trained teachers, are quite new to the students. Moreover, such illustrations seem to have a decided advantage in having been prepared originally by or under the direction of specialists. It is obviously im-

possible for the author of a general textbook, touching here and there over the wide field of biology, to improve upon the many classical figures whose obvious merits have caused them to be chosen for various textbooks. Having this view of the value of certain standard figures, the authors have chosen to use them, even in some cases when new illustrations were available and offered the possible attractiveness of novelty to some teachers.

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INTRODUCTION TO BIOLOGY

CHAPTER I

PRELIMINARY STUDIES OF LIVING AND LIFELESS THINGS *

1. **Biology, Botany, and Zoölogy.** — Biology is the science that treats of life and all living things — plants, animals, and man. There are two subdivisions of the science; namely, *zoölogy*, treating of animals, and *botany*, treating of plants. Zoölogy is often called *animal biology*, and botany, *plant biology*.

The division of biology into botany and zoölogy does not mean that plants and animals are entirely unlike; but, on the contrary, we shall find later that these two kinds of living things have many points of remarkable similarity in both structure and activities. This similarity is especially striking in many microscopic living things which so combine both plant and animal characteristics that biologists have not decided whether they are animals or plants. But although there is often a great similarity between animals and plants, it is sometimes convenient to study the two kinds of living things separately, and so biological science is sub-

* To Teachers: This chapter contains subject-matter which is needed in the study of biology, but with which few students in the early years of the high-school course will be familiar. Many teachers will prefer to omit §§ 5–29, and refer to them when they are directly applicable to the immediate lesson, as suggested in a foot-note to § 60.

divided into botany and zoölogy. These two subdivisions of biology are most important for advanced students; but the best and most interesting beginning study is that which directs attention to the great facts common to all living things. This book for beginners is called "Biology," to indicate that it uses both animals and plants to illustrate facts and ideas which are true of all living things.

More important than the similarity of animals and plants is the fact that many animals are in structure and activities very much like the human body; and hence the study of animals and plants helps us to understand better the human body and its life-activities. Moreover, thousands of animals and plants profoundly affect human life. For example, they provide all the food-supply for mankind; many harmfully influence human health; and some, such as pet animals and ornamental plants, contribute much to the pleasures of life. Clearly, some knowledge of the science of living things ought to be of great interest to educated people, because it applies in so many ways directly or indirectly to human life. Recognizing this fact, it is the aim of this book (1) to call attention to the most important facts and principles to be learned by the study of some selected animals and plants, and then (2) to show how biological science applies to everyday human life. In short, this is an elementary book of applied biology.

2. Living and Lifeless Things. — All things that we know through our senses are either *living* or *lifeless*. This will be evident if we attempt to write the names of some common things, grouping them according as they appear to have life or not. It is not difficult to decide that air, soil, minerals, and water belong in the list of lifeless things, and that the common animals and plants are examples of the living; but we are puzzled by such objects as dry seeds, undeveloped

eggs of animals, some plants in the winter condition, and many microscopic animals which show no signs of life when dry. Are such things living or lifeless? Usually it is not possible to answer until time and proper conditions have given an opportunity for changes which suggest life-activities, such as occur during the germination of seeds or the development of eggs into young animals.

3. Organisms, Organic and Inorganic Matter. — Except in science study, we rarely stop to think of the facts brought out in the problem above; but for the purposes of our later work in science it is important that we stop and make such a survey as suggested above, and recognize clearly that in this world of ours there are two kinds of things, — the *living* (collectively called animals and plants) and the *lifeless* (*e.g.*, air, soil, water, minerals, etc.). Living things are in science commonly called *organisms*, and the substances of which their bodies are composed, or which they form, is *organic matter*. Lifeless substance which has not been formed by organisms is called *inorganic* or mineral matter. All substances, then, in living and lifeless things are composed of matter which, as we learn through our senses, exists in many different forms.

4. The Sciences. — Knowledge regarding the living and lifeless things of nature is systematically arranged in the *natural sciences*. A common division of these sciences is that into (1) the physical sciences (chemistry, physics, geology, mineralogy), and (2) the biological sciences, which are concerned with living things. We shall see later that there is much chemistry and physics used in the study of living things, and hence it will be made clear that these two sciences deal not only with lifeless things, but also with all substances and changes which are found in both living and lifeless things.

CHANGES AND COMPOSITION OF LIFELESS AND LIVING MATTER*

In our later studies of the activities of living things (animals, plants, and man) we shall need to have in mind some important facts and principles relating to the composition of both living and lifeless things and to the changes which occur in them; and these are outlined in §§ 5–10.

5. Three States of Matter. — It is most convenient to use the collective term *matter* for all substances composing the bodies of lifeless and living things. Soil, water, and air are forms of lifeless matter which are examples of the three states, *solid*, *liquid*, and *gaseous*, in which matter exists.

Matter in one of these states may be transformed into either of the other states. Thus water, which is ordinarily liquid, may be cooled and frozen into ice (the solid state), or it may be heated and changed into vapor or steam (the gaseous state). Iron and other common metals, which are ordinarily solid, may be melted into the liquid state and at an extremely high temperature may even change to a gaseous state. Liquid air is made by reducing the temperature to −312° F. by subjecting air to great pressure in powerful machines.

6. Physical Change. — In all such changes of matter from one state to another (from solid to liquid, or to the gaseous, etc.) the same substance continues to exist. Ice is only solid water, steam is a gaseous state of water, molten iron cools into solid iron, and sugar and salt will dissolve in water. In these cases there has been a change in the state of material, but not a change in composition. Such changes which do

* Students who have previously taken courses in chemistry and physics should read §§ 5–10 as a review of familiar facts from a new viewpoint.

not affect the composition of substances are called *physical changes.* The next two demonstrations are illustrations.

(*D*) * Dissolve some common salt in water. The salt evidently undergoes a change. (The mixture of the salt and water is called a *solution*, and since the salt dissolves, it is said to be *soluble* in water.) Evaporate the water. Taste the dry substance left. Has the salt been permanently changed by being dissolved in water?

(*D*) Mix some powdered sulphur and iron-filings, and then use a magnet to separate them. Evidently the composition of the sulphur and iron was not changed.

That branch of science which treats of the state of matter and its physical changes produced by heat, light, sound, electricity, gravitation, etc. was formerly called natural philosophy, but is now usually known as *physics*.

7. Chemical Change. — All matter is subject to another kind of change in which the composition is affected and new substances are formed. Ordinary burning of wood or gas, and dissolving baking soda in vinegar or other acid, are common examples. The substances burned, or dissolved in acids,

* Directions for practical work are printed in the smaller type throughout this book. Problems for individual work in the laboratory are marked (*L*). Most of the laboratory work requires the supervision of a teacher, but it will be found that most exercises require little or no apparatus and may be conducted in the ordinary class-room, if, as in many schools, there is no special laboratory.

The letter *D*, at the beginning of a paragraph in small type, indicates that the practical work suggested is recommended for demonstration by the teacher; but when marked *D* or *L* it may be assigned, if the teacher prefers, as a problem for the individual work of the students.

All subject-matter in the larger type is suitable for recitations. In most cases the laboratory problems and the demonstrations should be taken in regular order, because much of the text in larger type interprets and supplements the practical work. In preparing any section for recitation or examination, students should review the laboratory directions in small type, for many fundamental facts there given are necessary for the intelligent reading of the text in larger type.

are changed to other substances. Such transformations which affect the composition of matter are *chemical changes.*

(*D*) Burn a small piece of magnesium wire by holding it in the flame of a gas- or an alcohol-lamp. Is the powder left after burning the same substance and in the same form as the magnesium wire that you burned? (If magnesium wire is not at hand, a very narrow strip of zinc, or fine iron-filings, may be substituted.)

(*D*) Mix powdered sulphur and iron-filings, and heat (in a test-tube or on an iron spoon). Compare with the result of the experiment in § 6. The heat causes the iron and sulphur to combine, forming sulphide of iron.

8. Elements. — The nature of chemical change will be clear after some further consideration of the composition of matter. In *chemistry*, the science which treats of the composition and chemical changes of substances, we learn that all forms of matter — all living and lifeless substances in land, air, and water — are composed of about 80 elements, of which about 20 are very common. Some of these elements exist naturally in the solid state; for example, iron, copper, lead, sulphur, gold, nickel, silver, platinum, carbon, magnesium, aluminum, tin, and zinc. Some others, like mercury (quicksilver), are liquid; and still others are gases, of which the two known as oxygen and nitrogen constitute the greater part of the air.

Chemical Symbols. — For convenience in writing the names of the elements, chemists have adopted certain symbols or abbreviations. The ones which will be most needed for reference in this book are: H for hydrogen; N, nitrogen; O, oxygen; C, carbon; S, sulphur; P, phosphorus; Na, sodium (or natrium); K, potassium (or kalium); Fe, iron (or ferrum); Ca, calcium (lime). A table giving the full list may be found in any elementary textbook of chemistry.

9. Compounds of Elements. — Now, the elements have the power of combining with each other so as to form various compounds. To illustrate: the burning of magnesium is a chemical combination between magnesium and oxygen of the air — two elements are here united to form a new substance, which is a compound of magnesium and oxygen and is known as oxide of magnesium. Such a union of any substance with oxygen is called *oxidation*. The burning of coal is in part a combination between the elements oxygen and carbon, but coal contains elements besides carbon. All ordinary burning or combustion is an oxidation; that is, the forming of a combination between oxygen of the air and some other elements. In all cases of chemical change there is a combining of elements into new or different substances. Such substances composed of two or more elements are called *compounds*. Most of the materials in the solid matter of the earth are compounds; water, which is the most abundant substance, is a compound of the elements hydrogen and oxygen; and most of the materials in the bodies of animals and plants are compounds. Air, however, is not a chemical compound; the nitrogen and oxygen are not united into a new substance, but are simply mixed together, just as dry sand and sugar can be mixed without change of composition in either. Other minor constituents of the air will be mentioned later.

Using the chemical symbols for the elements, chemists write MgO for magnesium oxide formed by burning magnesium (Mg) in the oxygen of the air, ZnO for zinc oxide formed by burning zinc in the same way, and FeS for the compound formed by heating a mixture of iron and sulphur (§ 8). The formula MgO expresses the composition of a molecule of magnesium oxide and means that it is made up of one atom of magnesium united with one of oxygen. This

is an example of the simplest possible compound. In most compounds of two or more elements there is a greater proportion of certain elements, and this is expressed by numbers after the elements of which there is more than one atom in the compound. Examples are: water, written H_2O, meaning that two atoms of hydrogen (H) are combined with one of oxygen (O); and sulphuric acid, written H_2SO_4, meaning that two atoms of hydrogen, one of sulphur, and four of oxygen are combined to form the acid.

In the above examples of forming compounds of magnesium and oxygen, iron and sulphur, there are two elements; but *more than two elements are often involved in a chemical change.* One compound of several elements may cause a chemical change in another compound.

(*D*) Ordinary baking soda is a compound of four elements — carbon, hydrogen, oxygen, and sodium ($HNaCO_2$). Put a piece of soda as large as a pea into a test-tube and pour on it some drops of vinegar, which also is composed of several elements. What happens? Does the liquid in the tube taste like baking soda or vinegar? Heat slowly and evaporate to dryness. Taste powder left in tube. Has some new substance been formed? In this case the elements of two compounds united to form two new compounds — the gas (carbon dioxide) which escaped into the air and the solid substance (sodium acetate) left after evaporating the water.

This dissolving of baking soda in acid illustrates the most common kind of chemical change, for most substances on the earth are compounds. It has been noted that the burning of magnesium involves only two elements, but the ordinary burning of coal and other common fuels is a union of compounds with oxygen, resulting in several new compounds in the smoke and ashes.

Disintegration of Compounds. — Not only may elements unite to form compounds, but these may be separated into simpler ones or even into their constituent elements. For

example, water may be formed by burning hydrogen gas so that oxygen of the air unites with the hydrogen as shown by the formula H_2O, but water may also be decomposed by an electric current passed through it in a suitable apparatus and the two constituent elements (hydrogen and oxygen) in gaseous form be collected separately. Such disintegration of compounds into the constituent elements is not so common in nature as is change of compounds into simpler ones.

10. Composition and Changes of Living Matter. — The principles stated in §§ 5–9 have been illustrated by lifeless matter, but we shall see in later lessons that they are also applicable to living matter. Plants and animals are composed of (10 to 15) common elements united in very complex substances; and in their bodies there are constant physical and chemical changes connected with all life-activities. Especially do foods eaten and oxygen from the breathed air become involved in numerous changes in the living matter of animal and plant bodies. Many times in later lessons we shall need to refer to the principles of chemistry and physics which §§ 5–9 review.

Summary: (1) Both living and lifeless matter undergo physical and chemical changes; and (2) all matter is composed of elements, usually combined in compounds, and capable under certain conditions of new recombinations into other compounds.

CHAPTER II

THE CHARACTERISTICS OF LIVING THINGS

CHEMICAL COMPOSITION OF LIVING COMPARED WITH LIFELESS THINGS

In order to understand the relations of living and lifeless things, we need to know whether the organic matter of living things is composed of peculiar substances which are not found in inorganic matter. A few simple experiments will show some remarkable similarity of composition.

11. Water in Living Things. — Water, which is itself lifeless, forms a large part of the bodies of animals and plants, as the following experiments show.*

(*D*) Cut leaves or pieces of stem from a green plant (preferably a succulent one). Slices of potato, apple, or tomato will make interesting comparison with the pieces of leaves and stem. Weigh the plant pieces with a good laboratory scale or a simple balance, place in a warm, dry place (*e.g.*, over a radiator, stove, lamp, or in sunlight). When very dry, weigh again. The loss in weight represents approximately the amount of water evaporated. What percentage of the original weight represented water? Keep the dry pieces of plant for the experiment in § 12.

(*D*) Carefully weigh some small bits of fresh meat. It is advisable to use an amount equal to the fresh plant materials in the preceding experiment. After drying thoroughly, weigh again, as was done with the plant materials in the first experiment. What percentage of the animal substance was water? Compare with the plant.

* In preparing for recitations and examination, students should review the laboratory work in small type and the illustrations, as well as the main text in larger type.

These experiments give us a general idea of the large amount of water in animal and plant bodies. It requires very careful experimenting with delicate balances for weighing, and special apparatus for drying, in order to determine the exact amount of water in plant and animal matter. Careful investigations by chemists have shown that the body of a higher animal (*e.g.*, a dog) is nearly 70 per cent water. This is believed to be true also of the human body. This water is derived from that which we drink and also from foods. Thus potatoes contain about 78 per cent water, milk 85 per cent, tomatoes over 90 per cent, apples over 80 per cent, and lean meat over 50 per cent.

It is evident that water must play an important part in the life of animals and plants; and in this connection it is interesting to note the abundance of water and its wide distribution over the earth. All good modern textbooks of geography emphasize the close relation between the distribution of water and that of animal, plant, and human life. Why are there so few living things in deserts?

12. Gaseous substances, which are themselves lifeless, may be obtained from the bodies of animals and plants.

(*D*) Pack the plant material left after drying in the experiment in § 11 in the bowl of a clay tobacco-pipe, close the mouth of the bowl with soft clay or plaster of Paris, support the pipe by a wire or by a retort-stand, heat the bowl in the flame of a gas- or alcohol-burner until it reddens and smoke (gases) begins to issue from the pipestem, then light the smoke with a match. One may heat some splinters of wood or sawdust and burn the gas in the same way. A piece of dried meat heated in the same way gives off gases, which may be burned. It is also possible to burn the gases from dry organic matter heated in a slender test-tube, or in one of the hard tubes known as ignition tubes.

Such experiments prove that combustible gases may be obtained from animal and plant substances after the water

has been removed. Chemists have shown that these gases are not present as such in the animals and plants, but the elements of which they are composed are united in chemical compounds which change to gas when heated. This will be clear when we recall that coal or oil (both of organic origin) when heated in retorts at the gas-factory, give off illuminating gas. Gas as such is not present in the solid coal, but it has compounds whose elements recombine when heated and form the gas. So it is in the bodies of animals and plants; the elements necessary to form the gases are present, and the gases are produced by heating, which causes new recombinations of elements.

13. Carbon is a prominent part of the solid substance of animals and plants. After the gases were given off in the preceding experiments, a black substance was left in the pipe. The same thing occurs when we burn an ordinary match; that is, certain gases burn and produce the flame and a charred mass is left. This black material we know as charcoal; at the gas-factory a similar substance from heated coal is called coke. The black color of coke and charcoal is due to the presence of an element known to chemists as carbon. The easiest way to get pure carbon is by charring white sugar with intense heat. Coke and charcoal contain other elements besides carbon. Chemists know more than one hundred thousand compounds of carbon with other elements. It is especially abundant in the organic compounds of which the bodies of animals and plants are composed, and consequently must be also in the food from which the body substances are made.

14. Mineral substances enter into the composition of animals and plants. If we reheat the charcoal obtained from either the animal or the plant matter in the preceding demonstration, by holding it with a wire in the hot flame of a gas-

or alcohol-burner, the carbon which it contains will soon burn; that is, combine with oxygen to form carbon dioxide (CO_2), and only mineral matter or ashes will remain. Another example is the familiar fact that when wood (or any plant matter) is burned there is formed a mass of red-hot coals or embers, which if allowed to cool quickly, becomes charcoal; but if the coals remain heated, they soon change to ashes, because the carbon is burned. Obviously, the charcoal obtained by heating ordinary animal or plant substances is a mixture of combustible carbon and incombustible mineral matter or ashes. Charcoal made by heating sugar leaves no ashes, because it is pure carbon, which in burning combines with oxygen and forms carbon dioxide.

A chemist could prove by careful analysis that the ashes from either plant or animal substances are a mixture of several compounds containing the elements calcium, sulphur, iron, potassium, sodium, and other elements. These are all found in the soils, and in the water of lakes, rivers, and seas.

15. Summarizing our inquiry into the composition of living things, we have found that water, carbon, gases, and mineral matters may be obtained by analysis of living things. All these substances are also found in lifeless or inorganic matter. It is evident then that chemical composition alone does not enable us to distinguish between living and lifeless matter. And yet in most cases we have no difficulty in deciding whether a certain thing is dead or alive. How do we know? The answer will be found in the life-activities.

LIFE-ACTIVITIES

16. Distinguishing between Living and Lifeless. — The conclusion reached in the preceding lesson was that all the materials entering into the composition of living things

(animals and plants) are also found in inorganic things, such as soil, water, and air; and hence animals and plants cannot be distinguished from lifeless things by the substances entering into their composition. What, then, does distinguish the living from the lifeless? Let us first try to answer this question by examining a living animal (*e.g.*, an insect or a frog) and, if possible, determine just how it is different in behavior from lifeless objects, such as a stone or a dead animal.

Life-Activities of an Animal

17. A living animal *moves* automatically or spontaneously. By this we mean that within the animal there is machinery for producing motion. A stone or any other lifeless thing can move only through the action of some external agency; it may fall (gravitation), or be moved by swiftly flowing water, by a violent wind, or by some animal. Not only do most animals have the power of locomotion, but also there are internal movements, such as breathing and the beating of the heart, which go on continuously as long as they live.

The statement that a living animal has machinery for producing motion reminds us of the steam-engine, but a little study shows that the engine is not automatic, as is the body of a living animal. For example, an engine requires the attendance of an engineer to supply it with water and fuel (that is, to feed it); but a frog is able to obtain its own food (fuel) and water to feed itself. Careful study of all machines invented by man shows that the movement which at first may appear to be as automatic as that of an animal is really dependent upon regular human attendance. Among common objects there is nothing lifeless which seems to have automatic movement, and in the vast majority of cases it is easy to decide that an animal is dead if there are no evidences of movement.

18. A living animal *requires food* if it is to continue to live and move and grow. This is a fact so well known that it needs no demonstration. There is nothing like animal growth among lifeless things. If a saturated solution be made by dissolving as much common alum (or copper sulphate) as possible in boiling water, and then a stone be dropped into the alum solution, the stone will be coated by alum crystals, but the stone will not increase. If a lump of alum be dropped into the saturated solution, the mass will increase by the addition of more alum crystals to the surface. This illustrates the fact that stones, crystals, minerals, and other inorganic things cannot add other substances to themselves and make them really a part of their own bodies. On the other hand, living animals can live and grow on food derived from other animals or from plants. For example, a frog may eat smaller frogs; but it may also eat earthworms or plants, and the substance of these will be changed and built into that of the frog. This power of a living animal to take food unlike itself and to make it over into its own substance is known as *assimilation* (meaning to make like or identical).

19. A living animal *breathes*, but a lifeless object does not. If we watch a frog, or a higher animal, we see muscular movements concerned with pumping air into and out of the lungs; and we call this process *breathing*. In many simple animals there are no lungs, but there are several ways of proving that they require air, and that they change the air when they breathe it. That land animals require air is shown by the fact that they die very quickly if placed in a jar from which the air has been pumped out with an air-pump, and aquatic animals will soon die in water from which the air has been withdrawn by an air-pump or expelled by prolonged boiling. The following experiment will

show a simple method of testing the changes produced in air which has been breathed: —

(*D*) Pour some lime-water or barium-water into a small bottle and blow air from the human lungs through a small glass tube (or straw) into the water. What happens? The change in the lime-water is due to a gas, called carbon dioxide, much of which is added to the air while it is in the lungs.

The same gas is formed by ordinary burning. Wrap a piece of wire around a small candle, light it, and then lower it into a tall, wide-mouthed bottle. After a time the flame will flicker out. Then lift out the candle and put in a little lime-water. Compare the lime-water with that changed by air from human lungs.

That carbon dioxide is in the air in a room or outdoors may be shown by exposing fresh lime-water in a tumbler until a white film forms on the surface of the water.

Take a tall, wide-mouthed bottle or fruit-jar, wash and rinse with fresh water, then lower into the jar a frog inclosed in a loose bag of cheesecloth or mosquito-netting with a string attached so that the frog may be lifted out quickly without inverting the jar or leaving it uncovered more than for a moment. One of the preceding experiments suggests that human breathing changes the air of rooms; and hence it is important that the jar be held at an open window where fresh air may enter while the frog is being placed in the jar. A good way is to keep the jar full of water until the moment when it is emptied at an open window and the frog placed in it. The water will prevent the jar becoming filled with the air of the schoolroom. A second jar, treated exactly like the first, but without a frog, should be kept beside the first for comparison. Leave the frog in the jar, carefully covered, for two hours, quickly lift it out, pour in 10 cc. of lime-water, replace cover, and shake. Did any change occur in the lime-water when it came into contact with the air which the frog had been breathing? Test the air in the second jar which has no frog.

The above experiments prove that some change occurs in air when animals breathe it. Until a later lesson we need not take time to consider just what this change is. For our present purpose it is sufficient to have shown that ani-

mals do change air when they breathe it, and that by means of lime-water we can demonstrate breathing of animals in which we cannot see breathing movements.

20. Living animals have the power of *reproducing* new animals like themselves. Frogs' eggs gradually develop into new frogs, and insects' eggs into insects of the species which produced the eggs. We shall later study the development of some animals from eggs, but for our present lesson it is sufficient to note that books on *embryology* (the science of development) state that all higher animals develop from eggs, which are small masses of living matter separated from the parent animals. No lifeless object has any such power of separating from itself a small body which is able to take food and grow into a body like the original one. The power of reproduction is, then, characteristic of living animals.

21. All animals after a time lose the power of moving, breathing, etc.; that is, they die. We are familiar with the fact that individuals of a given kind or species live for a certain length of time and then grow old and die. For example, an elephant has been said to live 200 years, a horse 40, lion 35, cat 40, toad 40, sea-anemone 50, crayfish 20, vulture 118, eagle 100, pike and carp 200, squirrel and mouse 6, pig 20, sheep 15, fox 14, and hare 10 years. However, it is certain that most individuals of these species live a much shorter life; for example, relatively few horses live over 20 years. The life of all individual animals, even though they escape accidents and disease, is of limited duration. They are like clocks wound up to run a certain period of time. Ultimately the machinery of life stops and the animal bodies rapidly decompose into substances which show no signs of ever having been alive.

22. Summarizing, we have seen that a living animal has the following activities: it moves; it breathes; it takes

food for assimilation; it reproduces. It has still other peculiar powers which will be considered later. None of these is found in lifeless objects, such as stones or dead animals. All such processes — moving, eating, breathing, reproducing — which are peculiar to living animals, are known as *life-activities* or functions. These are not permanent in any individual animal, for after a certain length of life the individual animal loses its life-activities — we commonly say that it dies — and the lifeless body soon changes to the condition of inorganic substances which make up air, water, and the soil of the earth.

Life-Activities of a Plant

To one who has never studied botany it may seem that most of the activities named above as characteristic of living animals are absent from living plants; but a careful examination shows that living plants move, breathe, require food, and reproduce, and in still other ways resemble animals in their life-activities.

23. Living plants have *movement*. It is true that most plants with which we are familiar are not capable of locomotion (*i.e.*, movement from place to place); but the same is true of many lower animals. On the other hand, there are many lower plants which have locomotion like that of some lower animals.

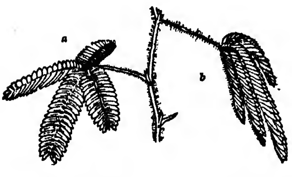


FIG. 1. The "sensitive plant" (Mimosa). *a*, expanded leaf; *b*, folded after being touched. (*After Detmer.*)

Locomotion in animals is only one phase of their movements; and much more impressive are the constant movements of internal organs, such as the heart and the lungs. There are many similar cases of plants

able to move certain organs, *e.g.*, the Mimosa (" sensitive plant ") moves its leaves and branches when touched (Fig. 1); the Oxalis, the bean (Fig. 13), and certain clovers fold their leaflets at night; the Venus fly-trap (Fig. 2) has peculiar leaves able to snap together and catch insects; many plants twine their stems around supports (Fig. 3); and plants bend toward the light when growing near a window. All such cases show that animals have no monopoly of movement. In addition to such plants which have locomotion and others which move leaves and other parts, there are in plants movements which can be detected only with the aid of a good microscope.

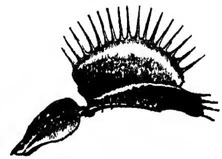


FIG. 2. Leaf of Venus fly-trap adapted for catching insects. (*From Strasburger.*)

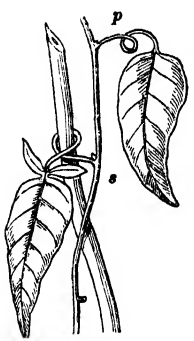


FIG. 3. The lower leaf-stalk (petiole) has twined around the stem of another plant.

(*D*) Examine any plants available which show any of the movements mentioned above. Many will be found at greenhouses. Leaflets of the Elodea (an aquatic plant) are excellent for the movements visible with the microscope. A piece of an oyster's gill will show microscopic movement going on in animals.

24. Plants require *food* if they are to continue to live and grow. It is a well-known fact that ordinary garden plants will not grow well unless there is in the soil a supply of fertilizer (a kind of crude plant food). It will be shown, in a later lesson, that green plants do not grow well if kept long in darkness, because light enables them to make in their leaves such foods as sugar and starch.

25. Plants *breathe.* In no plant is it possible to see breathing movements, as in some animals; but it is possible to prove by the lime-water test that changes are produced in the air by the breathing of plants.

(*D*) Take about twenty pea or corn seedlings (directions for raising such seedlings are given in § 81 of the "Applied Biology"). Place in a loose bag of netting, such as was used for the experiment with the frog (§ 19). Then lower the seedlings into a wide-mouthed jar filled with fresh air, and after 24 to 48 hours lift out the seedlings and test the air by pouring in some lime-water. A second jar without seedlings, but otherwise treated in exactly the same way, should be kept for comparison (control experiment). Take all the care suggested for the corresponding experiment with the frog. Compare results with that experiment. The breathing in the plants is so much slower than in animals that the same amount of change in the lime-water is not to be expected.

A potted plant, such as a geranium or a begonia, if placed under a bell-jar beside a small dish filled with lime-water and kept in the dark, will give proof that the plant causes changes in air, just as animals do when breathing.

In trying such experiments with seedlings or with any full-grown plants which have green color, keep the jar covered so as to exclude light. The reason for this precaution will be clear in a later lesson which deals with the effect of light upon plants with green color.

Other experiments connected with later lessons will give further proof that plants breathe, and will help to explain how they breathe.

26. Plants have the power of *reproduction.* We are familiar with the reproduction of many common plants from seeds and of others from cuttings or slips (*e.g.*, geranium, coleus, begonia). Many plants (ferns, mosses, horsetails, mushrooms, etc.) form small bodies, known as spores, from which new plants grow. And many of the microscopic plants reproduce by automatically dividing their bodies into two equal parts, and these half-size plants soon grow to the full size.

27. As in the case of animals, individual plants ultimately die, but some plants may live to a very great age. Some of the giant sequoias of California, the largest of which are nearly 300 feet high and more than 100 feet in circumference, are probably at least two thousand years old, and some botanists estimate that they are over four thousand years old. Some of the famous oaks of Europe are believed to be eighteen hundred years old, but our largest American oaks are probably less than five hundred. There are in Europe specimens of chestnut, olive, cypress, yew, and other trees which are probably much more than one thousand years old. It is impossible to estimate accurately even after the trees are cut down and the so-called "annual" rings of the trunk counted; but some of these trees were famous four or five hundred years ago, and they are certainly of far greater age than that which any animals are known to have reached.

28. Characteristic Life-Activities of Animals and Plants. — Our brief studies of a living animal and a living plant have shown us the following striking points of resemblance: (1) movement, (2) need of food, (3) growth, deriving the new substance from food, (4) breathing, (5) reproducing. All these activities or changes are found in living plants and animals and none of them in lifeless bodies. These are *life-activities characteristic of living things.*

We see, then, that in order to distinguish accurately between living and lifeless things we must determine whether there are evidences of life-activities. Every year dealers in seeds, gardeners, farmers, and the scientists at the government laboratories must test samples of seeds in order to determine whether they are living or lifeless. Chemical analysis will not settle such a question; and so the only way to test seeds is to put them under conditions where some

or all of the life-activities may be manifested. In short, the seeds must be planted under conditions favorable for growth. Likewise, dormant animals must be carefully examined for evidences of life. For example, small animals of certain species which are often abundant in soil where pools of water have dried up in midsummer may appear perfectly dead when viewed with the microscope; but they begin to move, eat, and manifest other life-activities soon after they are placed in water.

29. The Machinery of Life-Activities. — We have seen that certain activities in animals and plants make the living things different from the lifeless; and in Chapters III and V we begin the study of the structure and working of the living machinery which in the animal or the plant moves, takes food, breathes, grows, and reproduces. In order to understand the working of any complicated machinery, we must first take it to pieces and examine its structure, and later find out the use and work of each part. To this end we shall examine with considerable care the structure of certain animals and plants in the lessons that follow.

CHAPTER III

FIRST LESSONS IN PLANT BIOLOGY*

30. Plants. — The word "plant" usually calls to mind familiar trees, garden vegetables, and ornamental plants ("flowers"). In fact, most of the plants known to those who have not studied botany belong to the highest groups, which are often called the flowering plants. But the kingdom of plants is not limited to the *flowering plants* (also called *seed-plants*); for in addition it includes a vast variety of forms known in popular science as *flowerless plants*. Examples of these latter are ferns, mosses, toadstools and mushrooms, sea-weeds, molds, yeasts, and bacteria. Some of these are of microscopic size, and all are in general appearance quite different from the familiar flowering plants; but in many important respects there is much similarity. It is therefore possible by careful study of some common flowering plant to learn many interesting and useful facts that are common to plants in general. The common bean plant is excellent for this beginning study. It can be conveniently grown from seed planted in gardens or in boxes in the schoolroom from six to eight weeks before needed for study. The following account of the structure and life of a plant is based on the bean plant, but it will serve as a general guide for the study of any flowering plant.

* To Teachers: Chapter V, on insects, may precede these plant lessons, if it is desired to study insects in the early autumn. However, this and the following chapter need materials which are not so easily kept as are the necessary insects.

STRUCTURE OF A FLOWERING PLANT

31. Plant Organs. — If we examine any of the most common flowering plants, such as a bean plant, we notice first that it has several parts. These are roots, stem with its branches, buds, leaves, flowers, and sometimes fruits with seeds. These parts are *organs*. An organ of a plant or of an animal is a structure for doing a particular work; for example, lungs are organs for breathing. The roots, stem, leaves, and flowers are the plant's organs for taking food, for breathing, for reproducing — in short, for carrying on all its life-activities or *functions*. How can the organs of the plant perform these functions? In order to answer such a question, even in part, it is necessary that we study the general structure of the roots, stem, buds, leaves, flowers, and fruit.

The Roots

32. General Structure of Roots. — (*L*) Carefully dig up a young plant, and note how firmly the roots anchor it in the soil, and how the particles of soil cling to the small rootlets. Note that there is no definite boundary between root and stem.

That all the parts of a plant below the surface of the soil do not belong to the roots, as is popularly believed, is evident if we compare the roots of a bean plant grown from a seed planted four inches deep with those on a plant from a seed placed one inch deep in the soil. In both plants the roots are grouped at about the same place, and the deeper planted one has more than three inches of stem below the surface of the soil, but at first showing no roots. After growing six or eight weeks, other roots usually start from the stem nearer the soil surface. Stems of many kinds of plants will form roots if they are kept in moist soil.

The main root is called *primary root,* and the branches *secondary roots.*

On roots of some plants (clover, beans, peas, etc.) there may be seen small spherical bodies, some of them as large as one-eighth of an inch in diameter (Fig. 4). These are *root-tubercles*. In the later lessons on bacteria (microscopic plants), these tubercles will be referred to as caused by bacteria which are useful as makers of a peculiar kind of plant food supplementary to that furnished by manures or fertilizers in the soil.

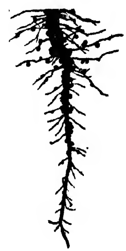


Fig. 4. Tubercles on root of bean.

There are on roots, especially on the younger branches, many delicate *root-hairs*, which are important absorbers of water from the soil. They are usually attached to the soil particles and are broken when plants are dug up and the soil washed from the roots. (Why are gardeners careful not to disturb soil around roots when transplanting delicate plants? Why are paper pots and egg-shells often used for growing young plants that are to be transplanted?)

Seedlings of radish, oats, clover, barley, and other plants, grown on moist blotting paper, are excellent for study of root-hairs.

(*L*) Examine a root and note that a layer of rind or bark (cortex, or cortical layer) is easily scraped or stripped from the central cylinder of wood. Test the strength of this central cylinder of a small root by pulling and by bending. How are strong roots of advantage to the plant? Tear a root lengthwise and note the fibers that make it strong.

33. Microscopic Examination of Roots.* — (*D* or *L*) Mount on an object-slide, with cover-glass, some small roots from Tradescantia stems that have been standing in water, or from seedlings of bean,

* To Teachers: This and later microscopic studies of plants may be abbreviated to leave only as much as can be seen with a hand-lens. However, at least one microscope is desirable for demonstrations.

radish, clover, oats, or barley, grown on moist blotting-paper. Using first the low power of the microscope, note (1) a cap-like structure on the tip of the root (Fig. 5), (2) a somewhat opaque central cylinder (Fig. 6), (3) a transparent rind outside, (4) the outermost layer of the rind is the very transparent epidermis.

Cells. — Now, using the high power of the microscope, it is easy to see that the root is composed of *cells* arranged as shown in Fig.

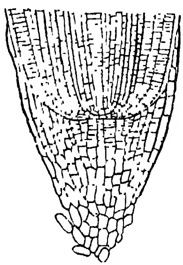


FIG. 5. Longitudinal section of tip of barley root, showing root-cap which covers the rounded end of the root.

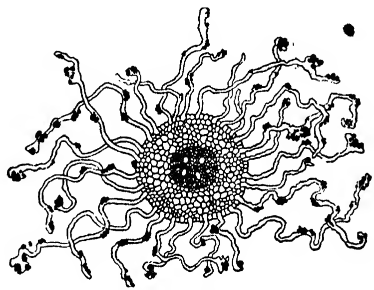


FIG. 6. Cross section of root, showing central woody cylinder; rind or cortex; root-hairs with particles of adhering soil. (*After Frank.*)

5. The boundaries of the cells, called *cell-walls*, are prominent; but within the walls may be seen a granular, semi-transparent substance, which is the living matter or *protoplasm* of the cell. Some dead cells with only the cell-walls remaining may be seen, especially in the central and older part of the root at some distance from the tip. In the central part of a root the walls of its constituent cells become hard and woody. All dry wood from roots or stems is composed chiefly of the walls of dead cells.

Growth of roots, and indeed of all parts of plants, is due chiefly to multiplication of the cells by division.

34. The Work of Roots. — The two primary functions of roots are (1) anchoring plants in the soil and (2) absorbing water in which are dissolved certain substances needed for growth of plants. Water enters the cells of roots chiefly

through the root-hairs. Certain roots (*e.g.*, parsnip, carrot, beet) store large amounts of food for the plant's use in the next growing season. The binding together of soil particles by roots is very important in preventing great erosion during heavy rains.

The Stem

35. General Structure of a Stem. — (*L*) The places where leaves are attached are joints or *nodes* of the stem, and the parts of the stem between the nodes are *internodes*. Compared with the hard and woody stems of shrubs and trees, the stem of the bean plant and of numerous common plants is soft (*herbaceous*); and soon after the formation of the pods (fruit) the plant begins to wither and then it dies. Hence the duration of life of a bean plant is one growing season; and such a plant which does not naturally live over winter is an *annual*. Name five other annuals.

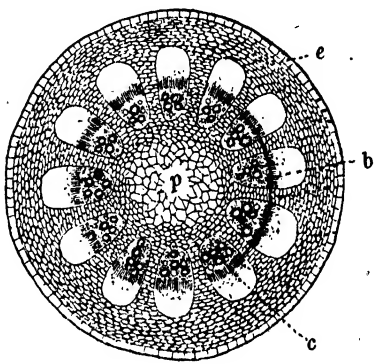


FIG. 7. Diagram of transverse section of one-year stem. *c*, cambium; *b*, a line marking boundary between central wood and the bark; *e*, epidermis; *p*, pith. Inside the cambium is a ring of groups of wood tubes (shown as small black rings). (*After Schmeil.*)

With a sharp knife, peel off the rind from the stem of a full-grown bean plant. Beneath the rind is the hard woody cylinder which constitutes the main body of the stem. For convenience we shall apply the popular term *wood* to the part of the stem inside the bark, *i.e.*, to the woody cylinder, remembering that in some stems there is soft tissue called *pith* especially abundant in the center of the stem. The wood is very soft in the young parts of stems, and resembles ordinary wood only when old and hardened. For example, the stem of a bean plant two weeks old is soft and brittle, but after six or eight weeks the oldest part of the stem becomes so woody that when peeled

it closely resembles stems of willow and other trees that are properly considered wood.*

Between the rind and the wood of the bean stem is a soft slippery substance or tissue which makes it easy to peel off the rind from the wood. The same kind of soft tissue may be found between the bark and wood of trees (willow twigs are excellent for examination).

In the center of the soft substance between the rind or bark and the wood of stems whose structure is similar to the bean stem, there is a layer of cells which are active in growth and division. This is the *growing layer* or *cambium.* On its inner side new wood cells are formed and added to the older wood of the stem, and on its outer side the new cells formed are added to the inner surface of the bark. Hence growth and division of cambium cells add new cells to both wood and bark, resulting in increased diameter of the stem.

On the outside of rind like that of the bean stem is a thin layer, the *epidermis.* Part of the rind is green in color, which is due to a substance most common in leaves and known as leaf-green or *chlorophyll.*

With a sharp knife or section-razor, make a cross cut (*transverse section*) of a bean stem. Examine with hand-lens, and note relative thickness of rind and wood. In the center of the wood is a softer substance, known as *pith;* and in an old bean stem there is a cavity in the pith.

(Optional.) Split open lengthwise (*longitudinal section*) a stem from an old bean plant, and note the extent of the pith and of the central or pith cavity. Tear the wood apart lengthwise, and note that it is " stringy." Pay special attention to the arrangement of the wood, bark, and pith in a longitudinal section of a stem where

* To Teachers: In applying the term "wood" to the woody cylinder of the stem, it is evident that wood is not synonymous with xylem. That which is popularly called "wood" includes the medullary rays, which are parenchyma from the standpoint of histology. Hence wood in the popular sense — and it is a popular and not a scientific word — is a combination of xylem and parenchyma, except any very soft central parenchyma which is commonly recognized as pith. For the purposes of elementary plant study the histological distinctions between the tissues of the woody cylinder of stems are of little significance, and so the word "wood" is used in this text as it is used by all the world except some writers who try to make it a synonym for xylem.

it branches. Make diagrams showing position of rind, cambium, wood, and pith.

36. Microscopic Study of Stem. — (*D*) With a razor or very sharp knife cut a very thin transverse section of a bean stem, mount in water on a glass object-slide. Examine with low power the rind and its outermost layer (epidermis), the wood, and the pith. Use a higher power of the microscope, and observe the *cells*. In some of the cells the living matter or *protoplasm* is visible, but some cell-walls in the central part of the stem are older and contain no living matter.

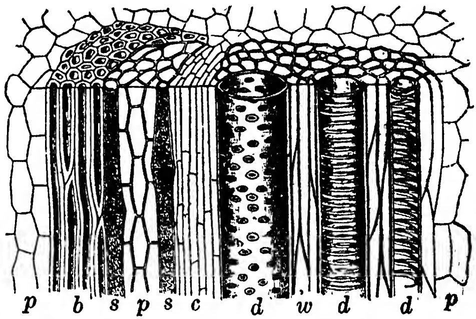


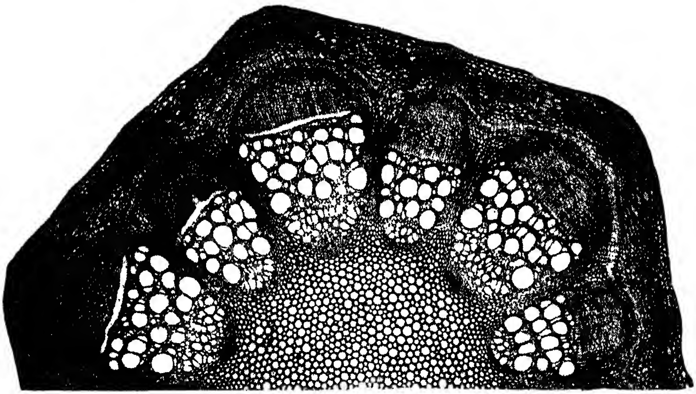
FIG. 8. Longitudinal section of fibro-vascular bundle of sunflower stem. *c*, cambium; *d*, wood-ducts; *b*, bast cells or fibers; *p*, pith or parenchyma cells; *s*, sieve-tubes; *w*, wood cells between ducts. (*After Wettstein.*)

In the outer part of the wood of the stem as seen in a transverse section are some large openings, which appear to be empty cells. These (see Fig. 7) are cut-off tubes, the *wood-tubes* or wood-ducts, in some of which water ascends the stem from the roots. The smaller and thick-walled cells surrounding the wood-tubes are hollow fibers (wood-fibers). Bend a bean stem from which the rind has been peeled, and notice its strength. Bend a very young piece of stem and notice that it breaks easily. The explanation of the difference between the two stems is that the tubes and fibers are not fully formed and hardened in the young stem. This is of practical importance in cultivating plants, for growing tips and young stems require more delicate handling than do the older and harder ones.

In Fig. 8, of a longitudinal section, it is shown that the woody fibers are long cells, and that some of the wood-tubes have peculiar spiral and ring thickenings of their walls, while others have numerous thin spots (called pits).

Notice in Fig. 7 and in a transverse section that the wood-tubes are in groups. In annual stems like the bean and in the first year of

our common trees and shrubs * the groups of wood-tubes are arranged in a single ring in the outer woody part of the stem and just beneath the bark (Fig. 9). In the inner part of the bark and opposite the groups of wood-tubes are other very small tubes and fibers. The cambium lies between the tubes and fibers of the bark and those in the wood. The tubes of the bark are called *sieve-tubes* (because of sieve-like partitions at intervals in the tubes); and they serve



p c

FIG. 9. Photomicrograph of half of a transverse section of clematis stem. Six fibro-vascular bundles shown. *c*, cambium, which was accidentally split in the three bundles on left side of the picture. Center of stem filled with pith (*p*) cells, which extend outwards between the bundles. Note the wood-ducts in the inner part of each bundle. (*Photograph by E. F. Bigelow.*)

to conduct sap down the stem. Groups of the bark fibers (often called bast fibers) are the " strings " seen when the bark is shredded into strips.

In some young stems, such as those of dutchman's pipe, the tubes and fibers on the two sides of the cambium are massed so as to make groups like the six shown in Fig. 9. These groups are called *fibro-vascular bundles.* Notice Fig. 9 carefully and observe that the cambium (*C*) marks each bundle into an outer or bark part and inner woody part.

* All plants of the groups dicotyledons and conifers.

In many common stems, the tubes and fibers are not so definitely massed in separate groups or bundles, but they form a more or less complete ring as shown in Fig. 10. But even in such stems it is possible to recognize as a fibro-vascular bundle the group of tubes and fibers inclosed within the oval ring in Fig. 10. Every such group is equivalent to one of the six bundles shown in Fig. 9.

(*D*) Exhibit a transverse section of a first-year stem of Aristolochia (dutchman's pipe) or clematis, compare with Fig. 9.

(*D* or *L*) The location and the work of the wood-tubes may be shown as follows: Cut off a fresh bean or similar stem, and stand its lower end in red ink (eosin solution) for a half-hour. Carefully strip off the bark and notice the position of the red color in the wood. Make transverse cuts in several places and examine with a hand-lens. Also, split longitudinally the wood of a stem into which red ink has ascended, and examine.

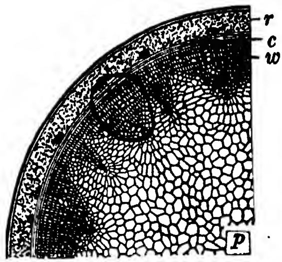


FIG. 10. Diagram of one-fourth of a transverse section of a sunflower stem. *r*, rind; *c*, cambium; *w*, wood-ducts. The ring marks the equivalent of one bundle in Fig. 9. (*After Frank.*)

To sum up statements made above, water from the roots goes up the stem in the wood-tubes that are just within the cambium, and fluids go down in the tubes of the bark (*sieve-tubes*) that are just outside the cambium. Thus the "circulation" or movement of fluids up and down the stem is confined to the inner part of the bark and the outer part of the wood.

37. Two-Year and Older Stems. — All the foregoing relates to stems whose structure is like that of the bean and which live less than a year and also to the first-year stems of our common trees and shrubs which live a number of years.

Transverse sections of two-year, three-year, and older stems from ash, oak, chestnut, and many other trees show more than one ring of large wood-tubes, usually a ring for each year of growth (" annual rings "). These rings of wood are produced by the cambium whose cells grow and divide so as to add new cells both to the wood and to the bark. Thus the woody part of the stem is continually increasing in diameter and the bark would become thicker each year if it did not scale off on the outside almost as fast as new bark is formed by the cambium.

Many stems, such as those of oak and beech, have prominent lines radiating from near the center. These are the medullary rays, sometimes called pith-rays because composed of compressed masses of pith cells. These rays will be studied later in connection with the economic uses of woods (§ 300). In old trees the tubes in the dead heart-wood do not carry water. This explains why the centers of trees may be rotted or burned out, and the trees continue to live as long as a layer of wood just beneath the bark remains healthy.

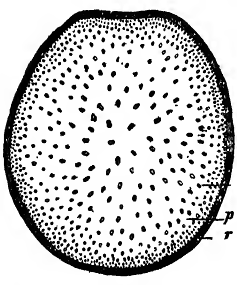


FIG. 11. Transverse section of corn stem showing rind (r), pith (p), and numerous fibro-vascular bundles (v).

38. Another Type of Stems.—The stems of corn, lilies, grasses, and many other plants of the groups known as monocotyledons (§ 44) have a structure different from that described in the foregoing which relates to the plants called dicotyledons and also to the conifers. The main difference is that in stems like that of corn there is no cambium layer, and the fibro-vascular bundles are scattered irregularly in the stem (Figs. 11 and 12).

Structure of Corn Stalk. — (*L*) Cut a dry corn stalk (stem) transversely. The smooth rind is on the outside, and inside the rind is the soft pith throughout which fibro-vascular bundles are scattered irregularly.

Split a stalk lengthwise, and the fibro-vascular bundles appear as long threads which are easily pulled out. Trace these long threads through nodes. Do they all continue upward, or do some of them turn toward the rind at the nodes? Try to trace some of the bundles out into the bases of leaves left on the nodes.

(*D*) Stand a piece of green corn stem for a short time in red ink, and then cut both transversely and longitudinally in several places, and note where the colored liquid ascends the stem. Each fibro-vascular bundle in the corn stem has an upward movement of fluids (air and water from soil) in the large tubes in the part of the bundle directed towards the center of the stem, and a downward movement in the small sieve-tubes in the part of the bundle towards the rind (see Fig. 12).

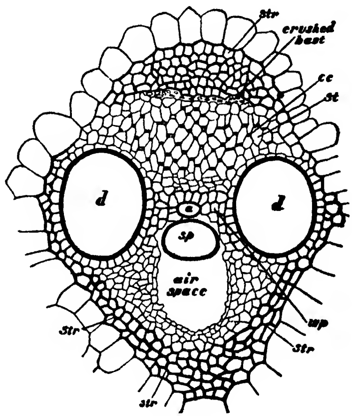


FIG. 12. Transverse section of a fibro-vascular bundle in corn stem. Lower part of the figure is towards center of stem. *a*, *d*, *sp*, ducts or wood-tubes; *str*, strengthening fibers; *st*, sieve-tubes; *wp*, woody pith. (*From Osterhout.*)

(Optional.) Examine with a microscope a thin cross section cut from a green stem, or from one preserved in alcohol or formalin solution. Observe that all parts of the section are composed of cells most of which are thin-walled *pith-cells*. Scattered irregularly among these are the fibro-vascular bundles. See the "Applied Biology," § 161, if fuller notes are wanted.

39. General Functions of Stems. — The primary work of ordinary stems is (1) support of the leaves in positions adapted to their work (§ 43), (2) conduction of fluids between roots and leaves, and (3) breathing.

(1) In the work of support, stems make use of the elasticity and rigidity of woody tissues and also of turgidity due to water in the cells. A very young plant depends largely upon turgidity, for if water is withheld from the soil, the leaves and stems become wilted. A young Windsor-bean plant growing in a pot will illustrate this. If the soil be allowed to dry, the stem will lose its turgidity (become wilted) and will droop. If then water is added to the soil, the stem will become turgid and rigid with remarkable rapidity, and within two or three hours will be as erect as ever. Stems of older plants of most species do not bend over when water is wanting, for woody tissues furnish the necessary rigidity. A straw of wheat or rye is a splendid example of rigidity due to woody tissues arranged in cylindrical form.

(2) The work of conducting materials is, as we have seen in the bean plant, due largely to the tubes in wood and bark which are specially fitted to conducting liquids up and down the stem. Other cells of the stem also play a part in conduction of liquids, especially in the transverse or horizontal direction.

(3) Breathing by stems occurs through certain openings in the outside layers of tissue. The epidermis of herbaceous stems has stomata similar to those of leaves. Examine with microscope epidermis from such plants as bean, tradescantia, and begonia. In plants with corky bark the stomata are replaced by openings known as *lenticles* (meaning lens-shaped) or stem-pores. Good examples may be seen on young stems of cherry and plum. Notice that on the older parts of these stems the lenticles are elongated by growth. The holes in cork used for bottles look like holes made by worms, but they are lenticles. Examine a bottle cork and note the parallel holes which originally extended through the thick corky bark, thus allowing air to penetrate to the active cells.

In addition to the three functions named above, many stems have special work such as climbing, food storage, and even serving as leaves. Some of these are referred to in this book in §§ 294–307, and they are more fully treated in §§ 169–178 in the "Applied Biology."

The Buds

40. Position and Kinds of Buds. — At various places on a bean plant are buds, which will unfold later. Some of these buds will form flowers, and hence are called *flower-buds;* others will unfold as leaves and are therefore *leaf-buds.* At the ends of the main stem and its branches are *terminal buds* which, by growth, lengthen the stem and branches. If the terminal bud of the main or a branch stem be destroyed, lengthening of the stem will cease. For this reason gardeners often break off the terminal buds of climbing or pole beans (*e.g.*, limas) when they have reached a height of about six feet. This has the effect of sending into the developing fruits (pods) much of the nutriment which would have gone to make the useless extension of the stem.

(*L*) Examine *buds* on a young bean plant, (1) with reference to their position, and (2) separate carefully the parts of both a leaf- and a flower-bud.

Twigs and their buds (§ 294, § 295) may be studied at this time.

The Leaves

(*L*) Students who have not previously examined leaves should give some attention to the general form of such *simple* leaves as apple or beech and maple. Notice *blade*, *petiole*, *veins*, and *stipules* at base of petiole.

41. Leaf and Leaflets of Bean Plant. — (*L*) Bean leaves appear to be arranged in groups of three (Fig. 13); but they are really three parts or divisions of one leaf. Such a leaf is called *compound*, and the three divisions are called *leaflets.* The supporting leaf-stalk (*petiole*) is

attached at a node of the stem and can be easily distinguished from a branch of the stem, because the petiole has an enlarged and somewhat flexible attachment to the stem; and also because a longitudinal cut through the node shows that the leaf is attached chiefly to the rind, while a branch is attached firmly to the wood of the stem. Each of the leaflets is attached by a thickened joint similar to that of the petiole at the stem. These flexible joints of the leaf and leaflets allow the drooping of the leaves at night and on hot days (Fig. 13 *b*).

FIG. 13. *a*, leaf of bean with three leaflets on petiole; *b*, position at night. (*From Detmer.*)

Examine any one of the leaflets, and note that the expanded surface (*blade*) is a thin sheet of tissues supported by *ribs* and *veins*. The central rib is the *mid-rib*. Hold the leaflet up so that light may shine through it, and with a hand-lens examine the delicate veins (*veinlets*) between the ribs. Make an outline sketch showing the structure of a complete leaf and the detailed structure of one of the three leaflets; label all the parts named above.

42. Microscopic Structure of a Leaf. — (*D* or *L*) Any convenient leaf, such as tradescantia, may be used for this exercise. With fine-pointed forceps, strip off a very small piece of the thin transparent epidermis from both the upper and lower surfaces of a leaf, and mount for microscopic study with low power. The epidermal cells of some leaves are not as irregular as those shown in Fig. 14.

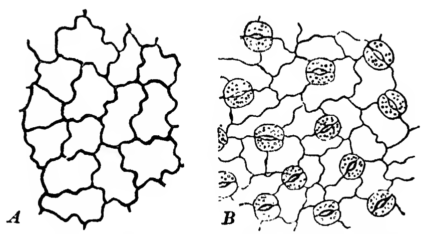


FIG. 14. Epidermis from certain plant leaves. *A*, upper surface. *B*, lower surface with stomata. (*From Strasburger.*)

Scattered among these irregular cells are pairs of crescent-shaped cells set together so as to leave a small pore or opening through the epidermis. Each pore is a *leaf-pore* or *stoma* (a Greek word meaning an opening, plural *stomata*). It opens into a small cavity (air-

space) beneath the epidermis (Fig. 16). Are the leaf-pores present and equally abundant on both upper and lower sides of the leaf examined?

These two crescent-shaped cells around the pore are called guard-cells. It has been noticed that when water is abundant in the plant these cells swell and become more crescentic in form, leaving a larger opening than when the leaf is drier. It is believed by most botanists that the guard-cells are able to prevent excessive evaporation of water from the air-spaces, and thus conserve water when necessary.

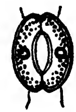


FIG. 15. Two stomata; one closed, one open.

Cut off a leaf transversely, and with a strong hand-lens examine the cut end. Note the transparent *epidermis* which covers both sides and the edges; that is, entirely surrounds the leaf. Between the upper and lower epidermis the center of the leaf appears to be filled with a green-colored, somewhat granular material (middle-tissue or mesophyll). Also notice the cut ends of the colorless veins.

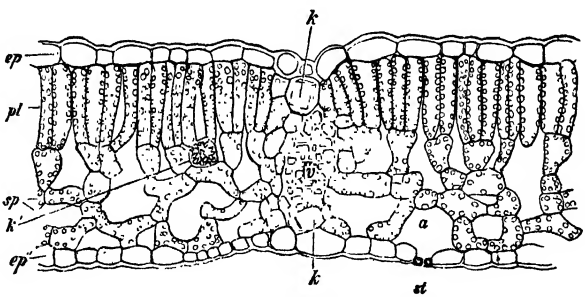


FIG. 16. Cross section of privet leaf. *ep*, epidermis; *pl*, palisade cells in upper part of middle tissue; *k*, crystals; *a*, air-spaces; *v*, vascular midrib; *st*, a stoma. (*From Strasburger.*)

If the hand-lens is a strong magnifier, it is possible to see that the green-colored middle-tissue is more compact toward the upper surface and appears to have small cavities in the part next the lower epidermis. This will be very clearly seen when the compound microscope is used for examining the cut end of a leaf.

(*D*) Examine with a microscope a very thin transverse section from the end of a leaf cut like the one described above. [To cut such a section, hold the leaf between two pieces of elder-pith, or slices of potato, or roll a leaf to form a rather tight cylinder. Keep the edge wet with water and with a very sharp razor shave off a number of very thin slices. Float these off the razor into water and with fine forceps or a small brush transfer these sections to a drop of water on a glass-slide and place the cover-glass in position.] Compare a transverse section with Fig. 16 and locate all the structures in the cut end of the leaf that was seen with the hand-lens. Note that the epidermis is transparent and without chlorophyll, except in the guard-cells at the leaf-pores. Compare with the epidermis which you previously stripped off and examined in surface view.

Most of the cells in the middle-tissue have green bodies (the chlorophyll-bodies, or chloroplasts). The compact upper part of this middle-tissue is seen to be composed of elongated cells (palisade cells) set closely together (Fig. 16). In the lower part of the leaf the cells are irregular in shape and there are numerous *air-spaces*. Some of these spaces communicate with the outside through the leaf-pores, and thus air may enter the leaf and become widely distributed throughout the air-spaces.

Also, in the middle-tissue examine the cut ends of the leaf veins. Wood-tubes in them are connected with those of the petiole which lead to the water tubes or wood-ducts in the wood of the stem.

43. The Work of Leaves. — There are three important functions of ordinary leaves: (1) evaporation of water obtained from the roots through the stem; (2) making sugar and starch from the elements in carbon dioxide and water, obtained respectively from air and soil; and (3) breathing or exchange of air in the air-spaces of the leaf through the leaf-pores or stomata. Each of these processes will be studied more carefully later (§§ 62–72). In addition to these three primary functions, the leaves of many plants are able to store food, catch insects for food, to serve as climbing organs and as protective prickles. Some of these special

forms of leaf functions are mentioned in §§ 308, 367 of this book and more fully in § 183 of the "Applied Biology."

44. Classification of the Bean Plant. — By this we mean the relation of the bean plant to other plants. In the first place, the bean plant is a member of the great *division* of flowering plants or seed-plants. Within this division are many families, one of which is the *family* of leguminous plants (including peas, beans, vetches, clovers, locusts, and numerous other plants which have irregular flowers similar to those of the bean plant). In this family are included a number of bean-like plants which are somewhat different from ordinary garden beans (*e.g.*, Windsor beans and horse beans). The common garden beans belong to the *genus Phaseolus* and to the *species vulgaris*, hence the scientific name is *Phaseolus vulgaris*. The various kinds of ordinary beans are *varieties* of the same species. The Windsor and horse beans belong to another genus.*

The relation of the bean plants to other plants is shown in the table of classification below. It is one of the Dicotyledones in Division IV, the seed-plants.

(There are four divisions or primary groups of plants.)

Division I. Thallophyta (simplest plants).
- (1) Algæ (with chlorophyll). Examples: sea-weeds, many minute aquatic plants.
- (2) Fungi (without chlorophyll). Examples: molds, mushrooms.

Division II. Bryophyta. Examples: mosses and liverworts.

Division III. Pteridophyta. Examples: ferns, horsetails, lycopods.

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* To Teachers: Some teachers prefer to let students acquire gradually a conception of classification of plants or animals, while to others it seems best to take such opportunities as this section affords for presenting to the class considerations of the meaning of classification such as are given in Chapter VII of the "Applied Biology."

Division IV. Spermaphyta (or Phanerogamia).

(1) Gymnospermæ. Examples: cycads and conifers.

(2) Angiospermæ.

(*a*) Monocotyledones. Examples: palms, grasses, lilies, orchids.

(*b*) Dicotyledones. Examples: most of the common trees, vegetables, and "flowers."

The plants in Divisions I, II, III are often termed "Spore-Plants," "Flowerless Plants," or "Cryptogams"; while those of IV are "Seed-Plants" or "Flowering-Plants."

Flowers, Fruits, and Seeds. — These parts of flowering plants are not needed for the life of the individual plant, but only for production of new individuals, that is, for perpetuation of the species. Since in the first part of this course in biology we are chiefly concerned with the structure and life of individual animals and plants, it is most convenient and most interesting to leave the study of flowers, fruits, and seeds for Chapter XII, which compares the reproduction of many living things. However, they may be studied at this time by turning to §§ 335–343.

CHAPTER IV

THE WORK OF THE ORGANS OF A PLANT: AN INTRODUCTION TO PLANT PHYSIOLOGY

45. Plant Functions. — The preceding lessons have dealt largely with the bean plant; but all the facts to which special attention has been given are true of the vast majority of the plants which have roots, stems, and leaves. The one plant has been studied as a type or example of common plants. In the preceding lessons special attention has been given to structure, and functions have been mentioned only incidentally. We are now ready for a study of the working of the various organs of common plants of which the bean plant has been selected as an example. That division of biology which deals with the work or functions of the organs of plants is commonly known as *plant physiology*.

In order to carry on their life-processes, plants must have food, water, and oxygen, as all animals do. These necessary materials must be obtained from the soil and air by all ordinary land plants. This chapter on the physiology of plants is concerned with the work of plants in getting food, oxygen, and water and in using these materials in their life-processes. We shall study first the entrance and movements of water in plant roots, stems, and leaves; and then in later sections we shall consider how plants get and use food and oxygen.

46. The Need of Water. — In one of the first experiments we found that plants contain a large amount of water.

Moreover, any one who has ever cultivated plants knows that unless the soil is kept moist the plants will wither and die. Evidently water must be of great importance; and so it will be of interest to study (1) how water gets into the plant organs (root, stem, and leaf) and (2) what work water does in these organs.

47. Source of Water. — It is obvious that ordinary plants which have roots must get most of their water from the soil. It might be supposed that some water from rain and dew which wets the leaves is absorbed; but that this is exceedingly small in amount and insufficient may be proved by taking a potted plant and covering the soil with waterproof cloth so that rain and dew may touch the stem and leaves but not the roots. Under such conditions most kinds of ordinary plants would soon wither.

48. Water in Soil. — How can plants get water from soil which appears to be very dry? The answer to this question is that apparently dry soil is not without water. It is not necessary, or even desirable, for many plants that the soil be wet; that is, contain free water which might be drained off. On the contrary, it is best for most plants if the soil contains moisture in the form of thin films adhering to the particles of the soil. We have already noticed that the root-hairs adhere to the soil particles (Fig. 6), and therefore they are in the best possible position for absorbing water from the soil.*

49. Rise of Water in Soil. — For our plant studies the most important points concerning soil moisture are as follows: The water stored in the deeper layers of the soil sup-

* If the students working with this book have not in some previous science work had lessons on water in soil, some work in this line should be introduced. Osterhout's "Experiments with Plants," pp. 103–121; Burkett, Stevens and Hill's "Agriculture for Beginners," pp. 10–15, suggest good experiments.

plies moisture to the layers nearer the surface. This is due to capillary action or capillarity, of which good illustrations are the rise of oil in an ordinary lamp-wick and of coffee into a lump of sugar which just touches the liquid. Water is continually being lost at the surface of the soil, owing to evaporation and to absorption by plants, and it is as constantly coming up from below. But it may be lost by evaporation from the surface soil more rapidly than it can come from the deep layers, especially if the surface is hard-packed, as on a road, or if the surface is covered with large numbers of plants, such as weeds or grass, which take much water from the soil.

Mulching. — Excessive loss of water from the surface of the soil may be prevented by mulching, two methods of which may be illustrated by reference to potato cultivation.

(1) In the usual way, the soil is cultivated on the surface in order to kill weeds which use water needed by the growing potato plants, and in order to keep the surface of the soil in a dusty condition. This checks the capillary action a few inches below the surface and moisture comes up to within reach of the roots of potato plants, but not to the surface where it would be wasted by evaporation. Such a condition is known in agriculture as a *dust-mulch.* On many farms that are conducted according to modern scientific ideas, one may see on hot dry days in the summer the cultivating machines at work pulverizing the surface of the soil in order to keep in the moisture. This is the main secret of success in the "dry farming" in many western States.

(2) The second kind of mulch is illustrated by the following method, often successfully used in growing potatoes in dry regions and in dry seasons. The potatoes are planted shallower than usual and the entire field is covered with several inches of straw. The potato plants grow up through

the straw, but most of the ordinary weeds do not. The straw prevents evaporation of water from the surface, and in dry weather the soil is found to be moister than soil treated by the dust-mulch method. In fact, a great objection to the method is that the soil often becomes too moist after heavy rains. This method is often used in orchards, where the weeds and grass are cut and spread over the ground around the trees, instead of cultivating the soil to keep in the moisture.

(3) In arid regions it is necessary to irrigate in order to grow potatoes. If the water is sprinkled over the surface, much of it is wasted by evaporation and moreover the soil surface becomes packed so that there is much loss of water from the deeper layers of soil. Modern irrigation methods avoid these objections to surface sprinkling by allowing the water to flow in furrows about a foot deep and soak into the soil beneath the surface. When the soil is well soaked, the furrows are filled with soil, and then the surface is kept in dust-mulch condition. This method is extensively applied for conserving water in the irrigated gardens, farms, and orchards of the western States.

It is obvious from the foregoing account of water in soil that this is one of the most important problems connected with growing useful plants, and horticulturists and agriculturists have found it important to understand the scientific facts concerning the water of the soil and its use by plants.

50. Absorption of Water by Roots. — That pressure is developed when water is absorbed by the roots may be demonstrated as follows: —

(*D*) Cut the stem of a healthy plant near the ground, and attach a glass tube by means of rubber tubing as shown in Fig. 17 and put in a small quantity of water. Geranium, dahlia, tomato, sunflower, corn, many young shrubs and trees, and grape-vines have stems

which make it easy to attach the tube. Make marks on the tube, keep the soil moist, and note the rise of water in the tube for several days.

Instead of a straight tube, botanists often use an S-shaped tube, and fill the lower bend of the tube with mercury. Since mercury is 13.6 times heavier than water, it is easy to compute the height to which a column of water might be forced. The root-pressure of a grape plant is sufficient to force a column of water up 10 meters (how many feet?).

FIG. 17. *s*, cut-off stem of a plant; *r*, rubber tubing for attaching glass tube (*t*).

51. Work of the Root-Hairs. — How does the water concerned in root-pressure get into the root from the soil? This is the question which naturally arises in our minds when we observe the preceding experiment. Scientists have studied the microscopic structure of the roots of many plants and have found no openings or pores through which water can get into the root, and so they have concluded that the water must soak through or be absorbed through the walls of the surface cells of the root and especially through the walls of root-hairs. In order to make this method of absorption clearer we must try some experiments.

52. Osmosis. — (*D*) Select a cork that will fit firmly in the mouth of a " diffusion shell " (a membrane bag which may be purchased from dealers in scientific apparatus), bore a small hole in the cork, and into the hole fit a glass tube of small caliber, and 18 to 40 inches long. Fill the shell with dark-colored molasses, insert the cork in the shell, wrap and tie around the cork a strong coarse thread, and support with a retort-stand, wooden tripod, or otherwise, so that the diffusion-shell will hang in water (Fig. 18). Note the movement

of the molasses up the tube for several days. Change the water when it becomes discolored by exuded molasses. If the shell does not break, or leak at the cork, the column of fluid may rise to a height of 8 or 10 feet. The glass tube may be made longer by joining on other tubes with pieces of rubber tubing for the joints.

A piece of gold-beater's membrane, or of fish-bladder, may be tied over the large end of a thistle-tube, which has been filled with molasses. Support so that the membrane will be in water.

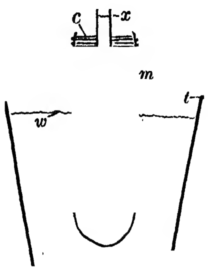

FIG. 18. Diagram of apparatus for osmosis. *t*, glass tumbler: *m*, membrane bag; *w*, level of water in tumbler; *s*, sugar solution in bag and up to level *x*; *c*, cork tied into mouth of the bag; *g*, glass tube of $\frac{1}{8}$ inch bore fitted into hole in cork. Rise of fluid higher than *x* indicates osmosis of water into the sugar solution faster than that of the sugar solution out into the water.

The membrane used for the above experiment has *no visible pores.* The entering water must pass through spaces which are far too small to be seen with the aid of the strongest microscope. Such diffusion or absorption of water or solutions through a membrane without visible pores is called *osmosis* (sometimes osmose) in the science of physics. The verb *to osmose* will be used in this book. For an explanation of osmosis one must study the advanced books on physics; but for the purposes of plant study it is sufficient to remember the above experiment as an illustration of osmosis.

A point needed for our later studies is that water having certain substances in solution may osmose. For example, in the above experiment the water became discolored by the exuded molasses (solution of sugar in water), proving that some of the molasses osmosed. Evidently the molasses did not osmose outward as rapidly as the water osmosed into the molasses,

otherwise the column of fluid would not have been forced up the tube.

53. Osmosis or Absorption by Roots. — The above principle of osmosis applies to the absorption of water by roots as follows: The cells of the roots (especially the root-hairs, Fig. 6) allow osmosis as the membrane of the diffusion-shell did. Thus water from the soil, containing mineral substances in solution, osmoses into the root. There is one difference between this osmosis in the root and that in our experiment; namely, that the cells of the root are filled with substances which attract water but do not themselves osmose out, as did the molasses. Hence water continually osmoses into the root, while the chief cell-substances do not osmose out into the soil. Some substances in root cells do pass into the soil but in very small quantities.

(*D*) That living plant cells control outward osmosis of their substances is illustrated as follows: Cut slices of a red beet root. Drop some slices into boiling water for a few minutes to kill the cells. Then put all the slices into cold water. Those heated give out their coloring substance rapidly to the water.

Recalling the pressure indicated by the height of the water column in the last two experiments, we note that in both cases pressure is the result of osmosis or absorption of water, in one case into the root by the cell-substance, and in the other case into the diffusion-shell by molasses. Roots, then, get the water from the soil by a process called absorption or osmosis through the delicate walls of the root cells, especially of the root-hairs.

54. In what part of the Root does Water ascend to the Stem? — Our experiment on root-pressure (§ 50) showed that water passes from the soil through the root into the stem. It has been stated that water gets into the root through its surface, particularly through the root-hairs, which greatly

increase the amount of surface cells for absorption. What is the path of water through the root on its way to the stem? The following experiment shows that water from the soil is distributed to cells by the wood-tubes.

(*D*) Cut off the small end of a slender root of carrot or parsnip, or of any other plant large enough for cutting sections; and place cut end of root in a bottle of red ink (eosin in water). After several hours cut transversely in several places, and note the position of the red-colored water in the tubes in the woody part (in fibro-vascular bundles, § 36). Some of the ink after a time soaks (osmoses) into the cells in the bark and pith of the root.

55. Why Water ascends Stems. — There are many evidences that water is continually ascending the stems of plants to the leaves. For example, if we cut off a stem, the leaves soon wither and dry up, while similar leaves with the natural connection to the root through the stem remain fresh and well supplied with water. We have already studied the rise of water from the soil into the root and from the root into the stem. What causes the water to ascend the stems of plants? This is still one of the unsolved problems of botany. Root-pressure, as we have seen, is enormous. In a young birch sapling it has been found to be great enough to raise a column of water 18 meters (how many feet?). But root-pressure alone is not enough to force water to the top of tall trees, and it does not move water upward fast enough to make good the loss by evaporation from the leaves on a hot day. There must be other factors in the elevation of water.

Another possible explanation is suggested by a simple experiment described on page 93 of the "Applied Biology," and illustrated by Fig. 19. A plant is cut off above the root and the stem inserted and sealed into a glass tube, which is filled with water and placed upright with its lower end dipping into mercury. When water is evaporated from

the leaves, the mercury rises in the tube (due to air-pressure, same as "lifting" of water by a "suction" pump). If mercury is lifted one inch, it indicates a force able to lift water 13.6 inches. In this way it has been determined that some shoots will lift water several meters. Evidently there is great lifting power or suction force caused by evaporation from the shoot.

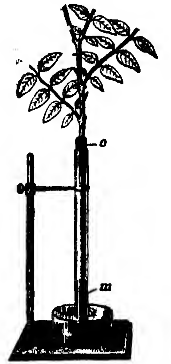

FIG. 19. Mercury "lifted" by evaporation from leaves. *m*, mercury; *c*, cork in end of glass tube and perforated to receive stem. (*From Strasburger.*)

That the "lifting" power is due merely to evaporation and not to some force peculiar to living plants may be demonstrated by tying a bladder or other membrane over a thistle-tube filled with water and suspended vertically so as to dip into a cup with oil or mercury. As rapidly as the water evaporates through the membrane, the oil or mercury rises in the tube. The apparent "suction" is the same as in a pump, and may be explained by the statement that atmospheric pressure on the mercury or oil forces it up the tube as rapidly as the water evaporates. The same explanation applies to the evaporation of water from the leaves in the preceding experiment.

Root-pressure, capillarity, and evaporation from the leaves are the best suggestions concerning the rise of water up the stems of plants; but botanists admit that even these working together do not explain how a plant can lift water as high as do the highest trees. This is only one of many hundreds of things in science which it has not been possible to explain satisfactorily; and in the attempt to get more knowledge hundreds of scientific men are constantly trying experiments in new ways.

56. In What Part of a Stem does Water Ascend? — Does water go up in all regions (bark, wood, and pith) of the stem? We can best answer this question by an experiment.

(*D*) Cut off a shoot (stem with leaves) of a nasturtium, balsam, corn, bean, or other plant, and place the cut end of the stem in a small bottle with red ink (solution of eosin in water). Watch the rise of the ink along the stem into the veins of the leaves. Now cut across the stem in various places and note that the red color is in the woody part. Cut a thin section and note that the red color is in the wood-tubes of the fibro-vascular bundles, which were mentioned in § 36.

If some stems be left in the ink for several hours, the sections will show that the ink osmoses from the wood-tubes into the bark and pith.

From such experiments as those above we conclude that the path of water up the stem is through the fibro-vascular bundles in the woody part of the stem. It was through these tubes that the water passed in our experiment on root-pressure (see § 50) and in that on evaporation (§ 55). From the wood-tubes water slowly osmoses into the cells of the bark and pith.

57. Water in Leaves and Evaporation. — In the last experiment the red-colored water ascended the stem and passed along the veins of the leaves. This was possible because the veins are bundles of tubes directly connected with the wood-tubes in the stem.

(*D*) Take a leaf from the bean or other shoot which was used in § 56. Scrape the petiole and veins so as to show the bundles of tubes colored by the red ink. Note (especially good in the leaves of bean and celery) the connection of the bundles of tubes in the veins of the leaf with the bundles of the stem; this is easily done by carefully scraping away the surface tissue from one side of the stem and petiole until the colored bundles of tubes are uncovered.

It is evident from the arrangement of the tubes and the path taken by the ink that water can pass directly from the

wood-tubes of the stem into those in the veins of the leaf, and thence into the numerous veinlets. In this way water coming up the stem from the root is distributed throughout the leaf, which is thin and greatly expanded so as to expose as much surface as possible to sunlight and air, and thus promote rapid evaporation. It is obvious that one purpose of the veins of the leaf is to distribute or spread the water so that it may be evaporated rapidly. That the arrangement is very efficient is indicated by the fact that the leaves of a sunflower plant six feet high have been proved to evaporate a liter (how many pints?) of water per day; and it was once carefully estimated that a large birch tree with about 200,000 leaves gave off 500 liters of water ($2\frac{1}{2}$ barrels) on a dry, hot day and probably averaged 60 to 70 liters per day during the summer.

Estimating Loss of Water from a Plant. — (*D*) Take a potted geranium, or other convenient plant, surround the pot and cover the soil with a sheet of rubber, tin-foil, or waterproof cloth, and tie carefully around the stem of the plant. Or set the pot in a battery-jar and cover the top with sheet rubber tied tightly around both jar and stem of plant. Thus only the upper stem and leaves will be exposed for evaporation. Now place the potted plant on a small platform scale (preferably one with two equal platforms which balance each other), and add the weights until there is an exact balance. Note from day to day the loss of weight from the plant. The tube of a glass funnel may be inserted through the waterproof covering into the soil, and a weighed amount of water poured in daily to replace the amount lost by evaporation.

In order to make evaporation more rapid than slow drying from the surface cells of the leaf, the leaf-pores (*stomata*) are sometimes opened, allowing watery vapor to escape from air-spaces in the leaf (Fig. 16). These cavities are surrounded by cells from which evaporation of water takes place rapidly. Thus the giving off of water is more rapid when the leaf-pores are open, and less when they are closed.

The leaves of many kinds of plants seem to have a very complete control of the amount of water evaporated, because in these species the covering cells (epidermis) of the leaves are thick and sometimes coated with waxy substances or hairs, and in still other ways are unfavorable for the evaporation of water from the surface of the leaf. In such plants evaporation appears to take place chiefly through the leaf-pores. When we remember that an ordinary cabbage leaf has ten million and a sunflower leaf thirteen million leaf-pores, we can easily understand how the opening and closing of these pores may control the amount of evaporation.

The process of evaporation of water from the leaves of plants is in botany commonly called *transpiration*, and we say that leaves *transpire*, meaning that they give off water by evaporation. For all practical purposes the words evaporation and transpiration are equivalent as applied to the work of leaves.

58. Soil-Water and Sap. — Throughout this lesson we have referred to water as ascending in the plant, but *it is never pure water.* Water absorbed from the soil always contains some mineral materials in solution. Also, as the water passes through the plant it absorbs or dissolves other substances and becomes *sap.* However, a large part of the water which goes directly up the stem in the wood-tubes is not very different from the water of the soil; and travelers in tropical countries often cut off certain vines and drink the water which runs from the stems.

One other point should be emphasized; namely, that in the evaporation of water there are left behind in the plant, especially in the leaves, all the substances brought in solution from the soil. Leaves which fall in the autumn give when burned much more ashes than do those which fall in the early summer; and the explanation is that evaporation

during the long summer season has left behind in the leaf various materials carried up in solution in water from the soil, and not needed by the plant.

59. Use of Water in the Plant. — So far in our study of water, its movement through root, stem, and leaves, and its final loss through evaporation, we have considered the purely mechanical processes without reference to the use of the water while passing through the plant. Now, plants are not elevating water simply for the sake of evaporating it from the leaves; on the contrary, evaporation is necessary to make place for more fresh water and so keep up the current from root to leaves. This is necessary for the following reasons: (1) The water carries up in solution indispensable food-materials obtained from the soil. (2) Water is necessary in many parts of the plant in order to give turgidity and rigidity. The wilting of plants when the soil is very dry is due to lack of water in cells and consequent loss of turgidity. A Windsor-bean plant growing in a pot is excellent for showing this. Allow the soil to dry until the plant wilts, then water the soil. (3) Water is necessary in order to dissolve sugar (*e.g.*, maple sugar and other sweet juices of plants) and other food-substances which must often be transported in solution from one part of a plant to another. (4) Water is needed because it is used in the manufacture of such food-substances as starch, sugar, and oils by the plant. (5) Water in large quantities is needed by growing plants because such a large proportion of the new substance is water. (6) Evaporation of water results in cooling the plant, thus preventing a dangerous amount of internal heat.

In addition to these special reasons why plants need water, we must remember that all living things require water (§ 11). Without water there is no life, so far as we know. Even seeds that are apparently dry contain a cer-

tain amount of water (8 to 15 per cent of their weight). Why are plants and animals not abundant in arid regions?

60. Food of Plants. — In addition to water, which may be estimated by weighing a plant before and after drying, there are other substances in plants and these must be derived from the food.* When chemists analyze the substances obtained from plants, by the methods used in the experiments of §§ 11–15, they find the following ten chemical elements: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), phosphorus (P), iron (Fe), potassium (K), calcium (Ca), and magnesium (Mg), in every plant. Still other elements are found in many plants, but they are not absolutely necessary for plant life. The first four (C, H, O, N) form the chief part of the combustible matter of all plants. These ten elements which are always found in plants must also be in their food, and in the next three sections we shall consider how plants get the food which will furnish these necessary elements for making plant structure.

61. Food-Materials from the Soil. — It is a matter of common observation that the growth of plants is largely influenced by the nature of the soil. Every farmer and gardener learns through experience to distinguish between barren and fertile soils, and that the addition of manures and various chemical "fertilizers" increases the growth of plants. The relation of plant growth to the materials available in the soil may be well illustrated by the following experiment.

(*D*) *Growing Plants without Soil.* — This may be done by germinating seeds of oats, beans, peas, lupines, and other common

* To Teachers: If Chapter II has not been studied, it is worth while to turn back and take up §§ 11–15 before considering the food of plants. If the students are unfamiliar with chemical elements and combinations, refer at this time to §§ 5–10.

plants on moist sawdust, cotton, sand, crushed stone, or other materials into which roots can penetrate, but which contain no plant food. When the seeds are well germinated, begin to moisten the sawdust or cotton daily with water in which have been dissolved some chemical tablets containing the materials such as are found in good garden soil; that is, the necessary elements (§ 60). If the roots are kept moist with such a solution of chemicals, some plants will develop flowers and seeds. By trying various chemicals in such experiments, it has been possible for botanists to prove that only certain elements are necessary in the soil for plant growth. Most of the elements are common in agricultural soils, but commercial fertilizers rich in nitrogen, potassium, calcium, and phosphorus are needed on many farms. The tablets may be purchased from the Agassiz Association, Sound Beach, Conn., for ten cents a box, postpaid.

Other interesting experiments in the same line may be performed by growing plants in different kinds of soils in pots, adding to the soils various kinds of plant foods and fertilizers sold for garden use (see catalogues of seed-dealers).

62. Food of Plants without Chlorophyll. — We can better understand how a bean plant or other green plant gets its food if we first study the nutrition of plants like the mushrooms and the Indian pipe, which have no chlorophyll. Such plants get their food-materials, containing the ten essential elements (§ 60), entirely from the soil in the form of (1) certain inorganic or mineral substances which are commonly found dissolved in water in good soils, and (2) organic materials absorbed from decomposing matter, such as leaf-mold, on which mushrooms and the Indian pipe commonly grow.

The water obtained from the soil by mushrooms contains compounds with the element nitrogen, and also in various combinations are other elements (*e.g.*, calcium, phosphorus, sulphur, potassium, magnesium, iron) which chemists find in analyzing such plants. These necessary elements may come in part from the decaying organic materials in the soil.

Now, only plants with chlorophyll can make sugar and starch,* and so mushrooms and similar plants must get such foods from some preëxisting plant which had chlorophyll; that is, they must live on leaf-mold or other decaying plant matter from which they can absorb such food. These carbohydrate foods which are absorbed by the cells of the mushroom are used by its protoplasm in its life-activities, especially in making new cell-materials into which the nitrogen and the other necessary elements named above are also combined.

Saprophytes and Parasites. — Plants that get their carbohydrate foods from decaying organic matter are often called *saprophytes* (from Greek words for "rotten" and "plant"). Many plants without chlorophyll are saprophytes. Some absorb the necessary food from living plants or animals, and such plants are *parasites* (*e.g.*, dodder, and mistletoe to some extent).

63. Food of Plants with Chlorophyll. — The common green plants have in their bodies at least the same ten essential elements as plants without chlorophyll. These elements, except carbon and some oxygen, are obtained from the soil, the hydrogen and oxygen in the form of water (H_2O), and the other seven in solution in water absorbed by the roots. The one fundamental difference between the nutrition of plants with and without chlorophyll is that the chlorophyll is a special substance with the aid of which the protoplasm of leaf-cells is able under the action of light to make the carbohydrate food (sugar and starch) needed by the plant, while non-parasitic plants without chlorophyll must absorb such food from the decaying bodies of other plants or animals.

* Sugar and starch are *carbohydrates*, a term which means a compound containing carbon (C) and water (H_2O), and therefore composed of the necessary elements carbon, hydrogen, and oxygen (C, H, O).

Cells containing chlorophyll are able to make carbohydrate food in the form of starch or sugar, obtaining the necessary elements from water, from the soil, and from carbon dioxide of the air.* This production of sugar and starch takes place chiefly in the leaves. Probably sugar is first formed and then changed into starch; but since starch is usually demonstrable in green leaves exposed to light, we shall give special attention to its formation. However, it makes no difference to the plant whether sugar or starch is formed in the leaves, for they are of equal value as food for all plant cells.

The stomata allow watery vapor to escape, in transpiration, and they are important also in allowing air with carbon dioxide to enter the spaces of the leaves, whence the carbon dioxide passes into the cells with chlorophyll (Fig. 16). Water reaches these cells by osmosing from near-by veinlets, which in turn receive water from the roots through the stem.

64. Photosynthesis. — That light is necessary for making carbohydrates (sugar and starch), the following experiment shows. Since the process is a synthesis or a combining depending upon the action of light, it is commonly termed *photosynthesis* (meaning combining by light). Briefly, it is sugar-making or starch-making in green leaves exposed to light.

Test for Starch. — (*D*) Put a small quantity of cornstarch in a tube with water, add a few drops of iodine solution (crystals of I in 70 per cent alcohol). Note the blue color. Test effect of iodine on powdered sugar in water. If we had time, we might test in the same way all the various substances found in plants and animals; but

* The atmosphere contains on the average about three parts of carbon dioxide in 10,000 of air, measured by volume; and yet from this exceedingly small amount of carbon dioxide the green plants get the necessary carbon for making all carbohydrates, which compose a large part of the solid matter of plants.

we must accept the records of science that no one has yet found any other substance in organisms which with iodine solution gives this peculiar blue color seen in starch. Hence we use iodine as a test for the presence of starch in animal and plant substances. Sometimes iodine is mixed with chloral hydrate in order to make it stain more intensely.

Starch Formed in Leaves in Light. — (*D*) Take two potted plants (bean, nasturtium, or other convenient plants), leave in a perfectly dark room (or box) several days, and some morning take one of the plants from the dark and set in sunlight. Near the close of the day take leaves from both plants, dip into boiling water for a minute, and place in bottles (labeled "dark," "light") containing strong alcohol. When the class meets again, note that the green color (chlorophyll) has been extracted by the alcohol ("bleached"). Take a leaf from each bottle, rinse in water, and place in a beaker or a small saucer containing some iodine solution (or better, use saturated solution of chloral hydrate mixed with enough iodine solution to color). In which leaf does the iodine test show presence of starch? Remembering that the two leaves have been treated exactly alike except that one came from a plant left all day in the sunlight, while the other remained in the dark, state your conclusion as to the importance of sunlight in starch-formation.

FIG. 20. The darker ends of this leaf were colored by iodine, indicating starch. The center had been protected from light.

Another way of showing the effect of light on starch-formation is as follows: Take a piece of sheet cork, or thick pasteboard, or tin-foil, about two inches square, and cut out a triangle, star, or any figure preferred, from the center. By means of pins or paper clamps fasten this on the upper side of a leaf of a potted plant, and a piece of black cloth or sheet of cork on the lower side; or cut the opening desired in a strip of tin-foil and then fold this around the middle of the leaf. Set the plant in bright sunlight with this leaf supported so that the upper side will get full illumination. Near the close of the day cut off the leaf, dip into boiling water, then place in alcohol for a day or two. Finally, test for starch with the iodine (or chloral hydrate and iodine) as in above experiment. Make a sketch

of the leaf, and by colored pencil or shading indicate where starch was formed. Label the portions of the leaf "exposed to light" and "in dark."

Variegated Leaves. — Many varieties of plants grown in greenhouses have "variegated" leaves with large white areas due to the absence of chlorophyll. That starch is not formed in these areas can be shown by taking a leaf which has been in sunlight all day and testing for starch as in the above experiments. Plants grown for a long time in a dark room lose their chlorophyll (*e.g.*, sprouting potatoes in a cellar), and after a day in sunlight their leaves show no starch. Why are the inner leaves of heads of lettuce and cabbage not green? How is celery bleached or "blanched"?

Intensity of Light Required. — It must not be inferred from the preceding that light must necessarily be in the form of bright and direct sunlight. Carbohydrate-formation is most rapid in sunlight, but probably goes on in light of all intensities, even in moonlight. This explains why some species of plants can live and grow slowly in shaded spots in the woods; they make use of the diffuse and weak light which reaches them. Moreover, light from other sources than the sun will serve for photosynthesis; for example, electric lights are sometimes used in greenhouses. The blooming of Easter lilies may be hastened from four to ten days; and lettuce grown within fifty or sixty feet of a 2000-candle-power arc-light, used regularly half of the night, will be ready for market a week or more before plants not so treated. Incandescent electric- and gas-lights have a similar effect, but in lesser degree.

Another illustration of the effect of light is in the rapid maturing of plants under the influence of the intense light of the short arctic summer. Also, plants in greenhouses in winter do not grow as rapidly in a given number of hours of

sunshine as they do in summer when the light is so much more intense. And this is so even when the interior of a greenhouse is constantly at the average summer heat.

65. Disappearance of Starch from Leaves. — Starch formed in leaves exposed to sunlight soon disappears, as the following experiment shows: —

(*D*) Take leaves from any plant which has been standing in sunlight, and place them in alcohol (§ 64) for testing with iodine later to make sure that starch is present. Then set the plant in a dark room or box for two nights, take other leaves before light reaches them, and soak in alcohol before applying iodine. There will be no blue color with iodine solution, thus indicating that starch has not remained in the leaves kept in darkness.

Where does starch go when it disappears from leaves kept in darkness? There are two answers: —

First, some of the starch has probably been used in the cells of the leaf, either changing to other cell-substances composed of the same elements (*e.g.*, sugar), or combining with the elements brought in water from the soil and forming compounds containing, besides the C, H, O of the starch, some N, S, and P, and perhaps other essential elements. The compounds thus formed (containing C, H, O, N, S, P) are called *albuminous* substances or *proteins;* and some of these may form some new living matter (*protoplasm*) in the cells of the leaf.

A second explanation of the fact that the starch disappears from the leaf at night is that it goes down into the stem or root, or into the developing flowers or fruits. That this is what occurs in part is proved by the fact that starch and other foods (*e.g.*, sugar, and oil with the same elements) are found in these parts of the plant, while all experiments ever tried have failed to show that these substances can be formed in cells without chlorophyll. The carbohydrate

foods needed in all living cells of a plant must be made in the cells with chlorophyll. Most of these cells are in leaves.

Starch in Cells. — (*D*) Thin sections of a potato will show the starch-grains in the cells. Stain some sections with iodine solution before mounting, or by drawing iodine under the cover-glass with blotting-paper. Using low power of a microscope, note the form of the starch-grains.

66. Digestion of Starch to Sugar. — How can such solid grains get through the cell-walls in going from the leaves and then into cells in other organs? The answer to this question is that starch is easily changed or *digested to sugar,* which is soluble in water and can osmose from cell to cell. This change from starch to sugar is caused by a substance known as *diastase,* which is present in cells of leaves and other organs of plants. This substance may digest starch at all times during the day and night, but the starch is formed during sunlight more rapidly than it can be digested. At night when starch is not being formed the diastase succeeds in digesting all the starch which was left in the leaf at the close of daylight. Hence, starch-grains are not found in leaves in the morning after being in darkness for several hours; but sometimes it is possible by chemical analysis to find in leaf cells sugar into which the starch has been changed and which either will be used in the leaf or will pass down the petiole into the stem.

Sugar Test. — (*D*) Boil a few grapes, raisins, or prunes in a test-tube with a little water in order to extract some of their sugar. Pour some of the extract into another tube, add a few drops of Fehling's solution (a mixture of copper sulphate and Rochelle salts, used by chemists for testing certain kinds of sugar), heat tube in a flame, and note the red color of the contents. Test some glucose or corn-sirup. Add Fehling's solution to a little starch in water; does the red color appear? Only sugars like glucose give the red reaction. White granulated sugar from cane and beet does not.

Change of Starch to Sugar. — (*D*) Boil a small quantity of starch in water in a test-tube, thus making a very thin starch-paste. Put half of the paste in a second test-tube and add some diastase (obtained by extraction from plant tissues, and sold at drug-stores). After a half-hour, take some liquid from each tube and apply the starch and sugar tests. Results? Conclusions?

Osmosis. — (*D*) Pour the contents of the two test-tubes into two gold-beater's bags and hang the bags in tumblers or beakers containing some water, or use the osmose-apparatus described in § 398. After allowing an hour or more for osmosis, pour some water from each tumbler into test-tubes, and test with a few drops of Fehling's solution. Also test some of the water for starch, using iodine. Does the starch-paste osmose? Is there sugar in the water having the starch without diastase? Conclusion?

67. Path of Foods down the Stem. — It has been stated above that the foods (chiefly sugar) made in the leaf may go down into the stem or into the other parts of the plant connected with the stem. Also, the proteins (compounds of C, H, O, with N and other elements) which are formed in the cells of leaves, may go down into the main stem and thence into roots, flowers, fruits, or new branches. Obviously the foods in solution cannot go down in the wood-tubes, because in them there is the upward current of water from the soil. Botanists are now agreed that the downward current is in the bark part of the fibro-vascular bundles, and through the tubes previously described as sieve-tubes (§ 36). The movement is so slow that it cannot be demonstrated with red ink, as in the case of the wood-tubes (§ 36). However, the evidence obtained as described in the next two paragraphs is no less convincing.

Effect of Girdling. — If a branch of a rose bush or other shrub be girdled (cutting away a ring of bark down to the cambium) and the injured region covered with wax to prevent drying, a thickened band of bark will slowly develop above the girdle, but never below. Evidently the tissue

above the girdle obtains more food for growth, and this must come down the stem in the sieve-tubes of the bark, for the wood continues to have the upward current of water from the soil. A branch will continue to live, but if the main stem is girdled the plant will die after some months, for the part of the stem below the girdle as well as the roots cannot get the necessary foods from the leaves and so they starve slowly.

Some trees die because an iron wire has been left wrapped around them until the stem has grown so large that the ring of wire becomes embedded in the bark down to the cambium, thus cutting off the sieve-tubes of the bark and preventing foods from reaching the roots. Farmers often girdle trees in early summer in order to prevent them from shading crops; but on some kinds of trees the leaves will remain green all summer if only the bark is girdled. In order to make the leaves of such trees wilt soon after girdling, it is necessary to chop through the bark and deep into the wood. Only the wood-tubes in the light-colored outer layers of wood, known to lumbermen as sap-wood, are important in the ascent of water; and therefore cutting deep into the sap-wood of a tree will cut off so many wood-tubes that the leaves cannot get water to supply loss by evaporation, and hence soon wilt. Even the hardiest trees, like the honey-locust, will ultimately die after the bark is girdled, because the supply of food, which came down from the leaves and was stored in the roots before the girdling, is gradually used up, and no more can get down to the roots.

It is possible for foods to go up a stem. The leaves of a branch that has a bunch of grapes might be cut off and the grapes would continue to grow, foods coming up the stem in the wood-tubes from other branches with leaves. In the spring before leaves appear on trees and shrubs, foods go up

the stem from the cells in root or stem where they were stored during the winter. If a branch of a tree be cut off in winter just above a bud, this will usually grow rapidly in the following spring and form a large branch. Orchardists make use of this fact when they prune trees. All these cases prove that the foods must be able to go up the stem. The upward movement is in the wood-tubes.

Summarizing, foods in solution in water (*i.e.*, sap) may be transported either up or down the stem, depending upon where the supply is located and where needed.

68. Use of Foods Transported from Leaves. — The sugar and other foods made in the leaves may be used in the plant in two ways, as follows: —

(1) *Used by Cells.* — We have seen that living plants require food, and this is true of every living cell. Some of the food from the leaves is at once used by cells in roots, stem, flowers, or developing fruits. Part of the food undoubtedly goes to make new particles of living matter (protoplasm) to replace that continually being worn out and made lifeless. It should be kept in mind that a living plant is like a moving machine in that activity causes wear or waste, and hence some food must be used for repair or the entire plant will soon die. In short, some food must be used continually in making new protoplasm. If more protoplasm is made than is needed for repair of waste, the result will be growth; and usually growth means the formation of new cells. This is especially true at the growing tips of plant stems. The making of new protoplasm is known as assimilation, or *constructive metabolism.*

(2) *Stored in Cells.* — If the foods received from the leaves are not needed for immediate repair, they are stored in various parts of the plant (stem, roots, leaves, or seeds). There are various modifications of plants adapted to storing foods;

but for our present purposes it will be sufficient to mention that carrots, turnips, and sugar-beets are examples of plants that store large quantities of plant food in their roots; sugar-cane and sago-palm store food in their stems; the head of a cabbage and an onion are bundles of leaves stored with food; and beans, corn, and nuts are seeds stored with food. These are examples of various plant organs in which food is stored for the future use of the plants. It has happened that man and the herbivorous (plant-eating) animals have found it convenient to appropriate many of these reserves of plant food for use in their own food-supply.

These reserved foods of the plant are commonly stored as starch, which is easily seen (with low power of microscope) in thin sections of various stems and roots, especially in the late autumn or winter after storage has been going on during the entire growing season. The sugar solution derived from starch in the leaves osmoses into the cells of the root, stem, or fruit, and is there changed and stored as starch-grains. When the plant needs this stored starch, the starch-grains are changed back (digested) again into sugar, which is able to osmose out of the cell and into other cells.

But all cells do not store starch. Sugar, from which our ordinary granulated sugar is obtained, is stored in large quantities in the cells of sugar-beets and in sugar-cane. Sometimes the sugar that enters cells is changed to oil, as in nuts; and when the plant needs food elsewhere the oil is changed (sometimes to sugar again) and osmoses out of the cells. In still other cases the sugar from the leaves enters cells and is used in combination with nitrogen and other elements from the soil to form protein substances.

Enzymes. — All these remarkable changes which take place when foods are stored in plant cells have long puzzled chemists. No one yet understands fully how the plant cells

are able to make these changes; but it is known beyond doubt that these changes do occur regularly in the life of plants, and further it is known that many peculiar substances called *enzymes* (*e.g.*, diastase) are present in plant cells, and that in some way not understood and not yet imitated in the chemist's laboratory these enzymes can change sugar into starch or oil, or these back into sugar. A peculiarity of enzymes is that they can change other substances without undergoing change themselves, and that a small quantity of enzyme can produce a large amount of change. The most familiar example of an enzyme is pepsin, which in the stomach of animals and humans digests protein foods.

69. The Oxygen-Supply of Plants: Respiration. — It has been pointed out that plants breathe or respire and have the same effect upon air that animals have; namely, they absorb oxygen from the air and give off carbon dioxide (CO_2). The term *respiration* is in both plants and animals usually applied to this combined process; but it is simpler to consider first how oxygen is obtained.

In a plant without chlorophyll (*e.g.*, a mushroom), oxygen is absorbed at all times of the day and night by the surface of the plant in contact with the air; and the gas then diffuses or osmoses from cell to cell, for all living cells must have a continual supply of oxygen. If some mushrooms be placed in a closed jar for many hours, it can be demonstrated by chemical tests that the air in the jar has lost oxygen. This will be the same no matter whether the jar is kept in light or in total darkness.

A bean plant kept *in darkness* in a closed jar will, like the mushroom, take up oxygen. The same plant kept in a closed jar *in sunlight* will give off oxygen. Apparently the reverse is true of the mushroom or the green plant in darkness; but let us withhold our conclusion until we have re-

viewed previous lessons dealing with carbon dioxide in leaves.

We have noted that carbon dioxide is used rapidly in making carbohydrates (in photosynthesis) while the plant is in light; but in darkness the plant makes no carbohydrates and consequently uses no carbon dioxide. Now, in the combining of the elements of carbon dioxide and of water to make sugar or starch, the carbon of the carbon dioxide is used, but the oxygen is not needed and is set free in the cells of the leaves.* The amount of oxygen thus freed is very much more than the plant needs for its oxygen-supply; that is, it is very much more than the same plant in darkness would absorb from the air; and the result is that there is excess oxygen to be given off to the air. The truth is that the living cells throughout the plant require oxygen both in light and in darkness; but while photosynthesis goes on so much oxygen is freed from carbon dioxide that the plant cannot use it all and gives off the excess to the air.

Oxygen Liberated by Photosynthesis. — (*D*) Place some water plants, such as Elodea, in a glass funnel which is then placed with tube upwards in a glass battery-jar filled with water. The water must be deep enough to more than cover the funnel and its tube. Fill a test-tube with water and, keeping its mouth below the water in the battery-jar, invert it over the end of the funnel tube. Set in sunlight. Bubbles of gas (chiefly oxygen) will rise from the plants and displace the water in the test-tube. The gas may be tested for oxygen by stoppering the test-tube before lifting from the water, and then quickly inserting a glowing taper when the stopper is removed.

* Readers who have studied chemistry will be interested in the proportions of CO_2, H_2O, and O in starch-making as follows: $(6\ CO_2 + 5\ H_2O)^x = (C_6H_{10}O_5 + 6\ O_2)^x$, which means that to every six molecules of carbon dioxide and five of water there will be one molecule of starch ($C_6H_{10}O_5$) and six molecules of *free* oxygen. This formula simply gives the proportions; for starch is some unknown multiple of $C_6H_{10}O_5$.

All kinds of plants, as well as animals, require oxygen constantly. They may get the necessary amount directly from the air, or green plants may get it from carbon dioxide during daylight. There is, then, no real difference between the breathing of mushrooms, animals, and plants with chlorophyll. The increase in oxygen and decrease of CO_2 in the air around green plants during daylight is obviously due to the independent process of photosynthesis, not to their breathing.

FIG. 21. Apparatus to show that air can enter the leaf. (*From Strasburger.*)

There are good reasons for believing that roots of plants absorb oxygen from the air which is abundant in good soil. In fact, one scientific reason for cultivating or tilling the soil is to mix air with the soil particles. The water of the soil contains oxygen in solution, just as the water in a river contains oxygen which fishes can absorb by their gills. When the water is taken up into the plant stem it probably carries along with it some oxygen, which is absorbed by the cells with which the water comes into contact.

Also, some of the large tubes of the fibro-vascular bundles are filled with air, probably taken in chiefly at the leaf-pores and also at the bark-pores (*lenticels*), which are slit-like openings in the bark leading to internal air-spaces. The following experiment shows how air may enter the leaf and pass through the stem.

(*D*) Select a wide-mouthed bottle and a stopper with two holes (Fig. 21). Take a leaf with a small round petiole and push the petiole into a hole in the cork and almost to the bottom of the bottle. Also fit a glass tube into the other hole of the cork. Fill

the bottle half full of water. Use vaseline to make the apparatus air-tight. Apply suction to the glass tube (a small bicycle pump with the leather on the plunger reversed, so as to " draw " air out, and connected by rubber tubing with a reversed valve from a bicycle tire will answer, if an air-pump is not at hand). Air will exude from the cut end of the petiole and appear as bubbles in the water. The experiment may be reversed by attaching the petiole to rubber tubing leading to a bicycle pump, and forcing air from the pump into the tubes of the petiole and out through the leaf, which should be held under water so as to make air-bubbles rise from the leaf surface.

70. Excretion of Carbon Dioxide from Plants. — The oxygen absorbed by plants and distributed to all their living cells is used in the cells in a process of slow oxidation or chemical union of oxygen with foods and other substances in the cells. This is the same as in animal cells. Such oxidation is constantly going on among the particles of living plant cells, and one of the substances formed is carbon dioxide (CO_2). When we remember that substances containing carbon are abundant in cells, we can understand why oxidation of cell-substances should form a compound of carbon and oxygen (CO_2). For example, when sugar is highly heated the effect is first to drive off the water and leave carbon, which then burns and disappears in the air as a gas (CO_2). Something similar occurs in living cells when any substance made from fat, protein or carbohydrates burns. The result is carbon dioxide (CO_2) and water (H_2O). The water thus formed cannot be distinguished from the other water which is abundant in plant cells. The carbon dioxide is transported (probably chiefly in solution in the moving liquids in plants) to the surface, especially of the leaves, and then diffuses to the surrounding air.

A plant with chlorophyll does not appear to give off carbon dioxide in light, because the carbohydrate-making is using that gas much more rapidly than the cells of the same

plant are making it. If any carbon dioxide made in the cells of the roots or of the stem is carried in the water current to the leaves, it may be used in starch-making; and in addition, the leaves must continually absorb more of the gas from the air. As has been stated, a closed jar containing a measured quantity of carbon dioxide and a green plant, placed in sunlight, will have less of the gas after a few hours; while a similar jar and plant kept in total darkness will have more carbon dioxide in the air of the jar. In the first jar, the plant used for carbohydrate-making all the carbon dioxide produced by oxidation in its own cells and in addition some of the gas taken from the air.

71. Other Excretions of Plants. — The term *excretions* is commonly applied to such substances as carbon dioxide, which are produced by oxidation in the cells of plants and animals, and which are eliminated because they are of no further use in the cells, and are sometimes actually poisonous. Carbon dioxide and water have been mentioned above as two excretions formed by oxidation of cell-substances containing the elements carbon and hydrogen. The water formed by oxidation mixes with the water taken into the plant by the roots, which is being eliminated continually by evaporation.

In addition to carbon dioxide and water, plant cells form other excretions and also have an excess of certain substances containing the elements absorbed with water from the soil. In higher animals all excretory and excess substances containing nitrogen, sulphur, phosphorus, calcium, etc., are in solution in the water eliminated by the kidneys. Land plants usually give off water only by evaporation, and certain excretory and excess matters are left behind in the plant (in the leaves) just as lime is left in a tea-kettle. Plants living in water may have some of these substances absorbed by the surrounding water. Also, plants may eliminate some sub-

stances by the roots, for the roots of some plants (*e.g.*, oat seedlings) will etch or corrode polished marble or limestone by the action of acid substances which osmose from the roots. Possibly these corroding substances enable a plant to dissolve useful minerals. Also, some grasses give off from their roots substances that poison and check the growth of young orchard trees.

As plants grow older the amount of stored substance, especially mineral matter from the soil, increases. See reference to mineral matter in old leaves (§ 58).

72. Irritability of Plants. — Irritability in either plants or animals is the power of responding to a *stimulus*. For example, if a frog be touched suddenly (mechanical stimulus), the leg muscles contract and the animal jumps. The frog also responds to heat stimulus (goes into shade when the sun's heat is too great); to light stimulus (sees enemies and jumps); to sound stimulus (hears sounds and jumps); electrical stimulus (jumps if touched by a slightly charged electric wire). These are phases or kinds of irritability common in animals which have a brain, spinal cord, and nerves.

We shall later study some microscopic animals which respond to mechanical, heat, light, and electrical stimuli; but they have no visible nerves or nerve organs. These lower animals have irritability or nervous functions without special organs to perform the functions. This is essentially the case in plants. In recent years there have been many magazine articles discussing "the nerves of plants." The truth is that no one has seen any nerves or brains or similar nervous organs in plants, although they do exhibit the various forms of irritability and respond to the different kinds of stimuli which affect animals, as the following examples will show: —

Mechanical or touch stimuli (such as a jar by passing

animals) causes the sudden folding of the leaflets and drooping of the branches of the Mimosa or sensitive plant (see Fig. 1). The leaf of the Venus fly-trap (Fig. 2) closes quickly and grasps insects which happen to touch it.

Response to light stimulation is seen in the familiar growing of house-plants toward the window, and also in the opening and closing of many flowers. Flowers of the dandelion and others of the same family, California poppy, etc., open in the light and close when placed in darkness.

Heat stimulus causes many flowers to open and close; tulip, crocus, and "star of Bethlehem" are familiar examples. The combined effect of heat and light stimuli upon the opening of flowers is so marked in many species of plants that it is possible to make a flower-clock, which is simply a garden-bed arranged to imitate a clock-dial, in which for each hour of daylight there is a selected group of plants whose flowers are commonly open at that hour. Of course, the flowers do not open exactly on the hour, for the controlling temperature and sunlight vary from day to day. However, many flowers are open in early morning; certain flowers (example, "ten-o'clock") open in the middle of the forenoon; others (like "flower-of-an-hour") open only in the mid-day sunshine; "four-o'clock" and others open in late afternoon; and the evening primrose at sunset.

Leaves of many plants (oxalis, clovers, bean, etc.) droop or fold in darkness and assume the so-called "sleep" position. Some so-called "compass plants" avoid the intense noonday sun by moving their leaves so that the edges are vertical and in the north-south direction.

Another form of external stimulus affecting plants is that of gravitation. That the stems of most plants ordinarily grow upward and the roots downward is a familiar fact. Experiments made by growing young plants attached to

rotating wheels prove that this direction of growth of plants in a state of nature is due to gravitation.

Plants also respond to water. Roots will turn away from dry soil and grow in the direction of greater moisture.

Still other forms of the responses of plants are the numerous cases of the twining of stems and the movements of tendrils and special roots in order to aid in climbing.

Tropisms. — We see that in many different ways plants have irritability and respond to external stimuli. The responses in plants are much slower than in animals, but they are none the less definite. These reactions of plants to stimuli are often known as *tropisms* (from a Greek word meaning to turn). Turning in response to light is heliotropism (literally, turning to the sun), or phototropism; to heat is thermotropism; to gravity is geotropism (literally, turning to the earth); to water is hydrotropism; to chemicals is chemotropism; to electricity, which seems to have little influence on plants in nature, is electrotropism. The same terms are used in describing the reactions of animals to the various kinds of stimuli.

Although these responses of plants to various stimuli have been observed and studied for a long time, we do not understand them. Neither do we know why a frog responds when touched. We simply know that it has the power of such response and that in some way it is connected with the protoplasm in certain special nervous organs of the frog. Likewise, we know many facts about plants responding in ways very similar to animals and that this power of response is connected with the protoplasm of plants, but apparently in no particular organs like nervous organs. We use the word irritability to mean that animals and plants respond to stimuli. We do not know what it is, but there is plenty of evidence that such a power exists, and we know much about

how it works. Likewise, we know that electricity exists, know much about how it acts, and can make great use of it; and yet no one knows what electricity is. These are merely examples out of hundreds of cases in science where we must accept the facts and make use of the knowledge which it is possible to discover even when we cannot find a satisfactory explanation.

73. Summary of Work of Plant Organs: Life-Processes. — Most plants require, as *food-material*, carbohydrates, nitrogen compounds, and certain other elements. Plants with chlorophyll can make the necessary carbohydrates by combining the three elements from carbon dioxide and water. Light and chlorophyll are essential for making carbohydrates. Plants which have no chlorophyll must absorb the carbohydrates (probably as sugar) from decaying organic matter. Nitrogen, in the form of compounds with other necessary elements, is commonly obtained from the soil or water in which the roots grow.

All plants require *oxygen* for use in the oxidation which is going on constantly in all living cells. Plants with chlorophyll may get oxygen from that which is freed from carbon dioxide when the carbon is used in starch-making. For this reason such plants do not appear to take oxygen in the daytime from the surrounding air, as they do at night, and as animals and plants without chlorophyll do both day and night.

All plants produce *excretions* by the oxidation going on in their cells. Most prominent of these is carbon dioxide, which all plants give off at night to the air or water in which they live. Plants without chlorophyll give off carbon dioxide in daylight also; but the green plants use this gas so rapidly when making carbohydrates that during the daytime none appears to be given off to the surrounding air.

All plants have *assimilation* or constructive metabolism of some foods into new protoplasm. This takes place only in living cells. Much of the food containing only carbon, hydrogen, and oxygen (*i.e.*, carbohydrates and oils) is believed to undergo oxidation in cells or is stored for future use, but does not become protoplasm. Probably only a small part of the contents of an ordinary plant cell is living matter, and much of the cell-substance which we see with the microscope consists of food-materials, water, and other lifeless substances.

Digestion of foods is necessary whenever insoluble foods (starch, oil, proteins) require transfer from cell to cell or to distant organs of the plant.

Moving liquids in the higher plants serve to transport the foods, oxygen, and excretions; but these liquids do not make a complete circuit as do the animal circulating liquids (blood and lymph), whose function is also transportation of foods, oxygen, and excretions.

Some form of *irritability*, or power of responding to stimuli, is present in all plants. But there are no special nervous organs, such as are connected with irritability in higher animals.

All species of plants have the power of *reproduction*. This will be considered in Chapter XII.

CHAPTER V

STUDY OF INSECTS: INTRODUCTORY LESSONS IN *ANIMAL BIOLOGY* *

74. Study of Insects. — The word Insecta is the scientific name for a large group of animals popularly called insects, and of which familiar examples are grasshoppers, cockroaches, flies, beetles, bees, and butterflies. Spiders are also popularly regarded as insects; but we shall see in later studies that they are different from all the familiar insects.

It is scarcely possible to find for beginning the study of zoölogy any animals more interesting than insects. Many insects have useful or injurious relations to man; *e.g.*, some destroy plants, some transmit the germs of disease to man and domesticated animals, and some produce such useful substances as honey and silk. All such relations of insects to man are said to be economic, and they will be considered in §§ 260–262, 319, 320. Aside from the domesticated birds and mammals, the insects are of more economic importance

* To Teachers: This study of insects may precede Chapters III and IV (see §§ 32–64 and 65–110 in the "Teachers' Manual of Biology"). September and October are good months for study of insects out-of-doors; but many of those most useful for this study may be kept in insect-cages (see the "Teachers' Manual of Biology," § 323); and thus make it possible to use the first five or six weeks of the school year for the study of plants according to the two preceding chapters. Natural history of insects is interesting and especially desirable for students who have not had the advantage of nature-study in the elementary school; but in high schools most of the outdoor study of living insects must be supplementary to regular work planned for laboratory and classroom.

than are all other groups of animals taken together. But quite apart from practical matters, the insects have long been favorite objects for study because many are beautiful, many have remarkable adaptations to special conditions of life, and many have wonderful instincts and nervous activities that are surpassed only by certain birds and mammals.

More than half of the known species of animals are insects. At least 250,000 species are now known, and many newly discovered species are named and described each year. Some experts in *entomology* (that division of zoölogy which deals with insects) believe that there may be living now a million species of insects.

In order to observe living insects satisfactorily, one must first know the general plan of insect structure and the uses or functions of the main parts or organs of their bodies. It is a fortunate fact for students that insects are all built on the same plan of structure, and that a study of a few selected specimens will enable one to understand almost any other insect which may be seen. Some of the many kinds or species of grasshoppers, flies, and butterflies are commonly used for introductory studies; but many other common insects might serve well for first lessons.

75. Study of a Grasshopper. — *Materials.* — For study of structure, either specimens recently killed (by chloroform, benzine, or cyanide) or some preserved in alcohol or formalin solution. Living grasshoppers in glass jars (*e.g.*, jelly glasses with perforated tin covers) with some green grass or other plants for food. Crickets, cockroaches, or katydids may be used as substitutes for grasshoppers, or for comparison.

Laboratory Study. — Place a grasshopper, or a similar insect, so that you can easily see its parts, carefully read the following laboratory directions and make sure that you see and understand each point before passing on to the next.

(*L*) The grasshopper consists of *body* and of legs, wings, jaws, and other projecting parts which collectively are called *appendages.*

Notice three regions of the body, — *head; thorăx*, with three pairs of legs; and a segmented or jointed *abdomen.* Notice that the body and appendages have a hard covering, and external skeleton. There is no internal skeleton as in the human body.

Just as in geography we use the terms north, south, east, and west to indicate directions, so in zoölogy we must have terms for directions or positions on bodies of animals. The head-end of a grasshopper is called *anterior*, the opposite end of the trunk is *posterior*, the lower surface of the body is *ventral*, and the back or upper surface is *dorsal.*

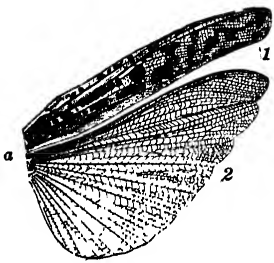

FIG. 22. Wings of a grasshopper. *a, 1*, anterior wing; *2*, posterior. (*After Joutel.*)

Any animal having differentiated (meaning "made different") dorsal and ventral surfaces, and anterior and posterior ends, might be divided into similar halves (right and left) by cutting in the median plane from anterior to posterior and from dorsal to ventral. Can you think of any other plane in which a grasshopper can be equally divided? Such an animal is *bilaterally symmetrical.* Do you know any animal which is not so? Animals, like jellyfishes, which have the wheel-like plan of structure are said to have *radial symmetry.* There are comparatively few such animals, but many plants are so arranged.

The word *organ* will be used frequently hereafter. An organ is a part of the body of a plant or animal fitted for doing a particular work. For example, the heart is an organ for pumping blood, lungs are organs for breathing, muscles are organs for moving. A group of organs doing similar work form a *system.* Thus, all the muscles constitute the muscular system, which is a group of organs adapted to the work of producing movement.

Abdomen. — The tip of the abdomen of the female bears two pairs of pointed structures which are of use in depositing the eggs, and together they are known as the *ovipositor.* The end of the abdomen of the male is turned upward. Count the rings or *segments* in the abdomen. On the first ring next to the thorax there is on either side a shining oval patch, the *organ of hearing.* Along each side of the abdomen is a groove, and just above it is a row of pores (spiracles or *breathing pores*). Watch the breathing movements of the ab-

domen of a living grasshopper. The spiracles are connected inside with a system of branched air-tubes (*tracheæ*), which ramify through the body and distribute air directly to the tissues. Compare this method of breathing, which is characteristic of insects, with that of the human body.

Thorax. — Each pair of jointed appendages (legs) represents a segment of the thorax. How many pairs of legs are there?

Look for the breathing pores on the second and third segments.

Examine the two pairs of wings and compare them as to form, size, texture, color, position, and use. The veins in the wings are hollow tubes which carry blood and air.

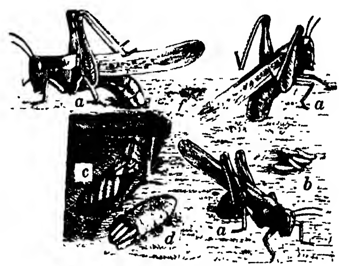

FIG. 23. *a*, egg-laying of grasshoppers; *b*, eggs; *c*, *d*, masses of eggs. (*After Riley.*)

The characteristic shrill sound made by katydids is caused by rubbing the upper wing on the lower wing.

Compare legs from each segment of the body which bears them. Are they similar? Observe the hooks and pads on the feet — these are used in clinging when the animal is at rest. Examine the legs that are adapted for jumping.

Head. — The head is attached to the thorax by a soft neck. Examine the large eyes with a hand-lens, and with a microscope examine a slice from one of the eyes. These characteristic insect eyes are *compound.* Also, many insects have several bead-like *simple eyes* (ocelli) situated on the head between the compound eyes (use hand-lens). Examine the long slender feelers (*antennæ*) with a hand-lens. Examine the *mouth-parts;* upper lip (labrum); lower lip (second maxillæ, or labium); first maxillæ beneath the upper lip; jaws (mandibles) between the lips; and a tongue-like organ within the mouth.

Make enlarged drawings of a grasshopper: (1) of side view with wings in closed or resting position, (2) of front view of head, (3) of a leg, (4) of side view of abdomen.

Examine young grasshoppers of various sizes. How do they differ from the adult specimens?

Observe method of locomotion, taking of food, kinds of food, and breathing movements of grasshoppers kept in glass jars. When opportunity offers, carefully observe them in the fields. Record your observations.

Grasshoppers are called locusts in the Old World, but rarely so in America. The so-called "seventeen-year locusts" are really cicadas, belonging to an entirely separate order of insects (the Hemipterans).

76. Study of Fly. — The house-fly is most easily obtained, but some of the larger species are better for laboratory study. Pieces of fresh meat left outdoors for a few hours will probably attract some of the "blue bottle" or "blow flies"; and they will lay.eggs. These will hatch within 24 hours, and the larvæ ("maggots") begin to eat the meat. Each day they may be brushed from the old to new pieces of meat, and thus avoid disagreeable odors. It is said that they may be fed with moist bran, oatmeal, or even soaked crackers. The larvæ are full grown within a few days and then pupate. The pupæ resemble small, brown seeds. Finally the pupal case breaks at one end and the perfect fly emerges. The house-fly pupa changes in about one week.

Flies do not grow after they reach the fly stage. Their formation of tissue takes place while they are voracious larvæ. The flies of many sizes often seen in houses are not young and adults, as commonly supposed; but all are adults of various species. The food of the larvæ is not the same for all species. The blow-flies commonly lay their eggs on meat; but the house-flies lay their eggs in manure and various kinds of filth. If disease-producing bacteria happen to be present in the filth on which the house-flies walk, these bacteria may later be left on foods. The piercing flies may inject certain bacteria into the blood of humans and animals. These relations of flies to disease will be considered in § 261.

(*L*) Examine a fly as you did the grasshopper, noting head, thorax, abdomen, legs, and wings. Does the fly have the same number of wings and legs as has the grasshopper? With a hand-lens, examine (1) the eyes; and (2) the mouth-parts (in some species adapted for rasping and lapping, in others for piercing and sucking). Examine the feet with hand-lens.

Examine a larva with hand-lens. The head is small, the body is segmented, and there are no feet. Examine a pupa. Only the brown protective case can be seen.

77. Study of Butterfly, or Moth. — (*L*) Examine a butterfly with regard to the points of structure already seen in a grasshopper. The chief differences to be observed are: (1) Large wings covered with *scales* (use hand-lens and microscope). On some butterflies and on moths there are hair-like scales. (2) Legs of butterflies are adapted for clinging, not jumping. (3) Antennæ are club-shaped on a butterfly, feather-like on a moth. (4) Mouth-parts are adapted for sucking nectar of flowers. There are no jaws for biting solid food, but a long coiled tube, consisting of two halves closely applied together, is the sucking organ. However, the butterfly is, on the whole, built on the grasshopper plan of structure.

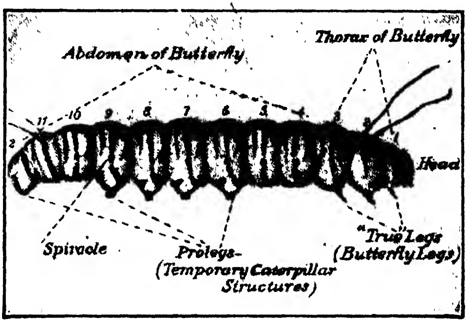

FIG. 24. Butterfly larva. (*From Dickerson's "Moths and Butterflies," Ginn & Co.*)

Larva.—Most remarkable about butterflies and moths is their peculiar development from *egg* to *larva* (caterpillar), then to *pupa* (which may be in a silky *cocoon*), and then to perfect insect (*imago*).

The larva called "tomato-worm" (which develops into a hawk-moth) is excellent for study. Observe: (1) Head, and its parts. (2) Thorax, with three segments, each having a pair of legs. (3) Next are some segments with no legs, and then come several segments with peculiar legs adapted to clinging to twigs (prop legs). (4) A curved spine at posterior end. (5) Spiracles or breathing pores along the sides of the body. (6) Color markings in living specimens, if available. Make an outline drawing of the larva as seen from its right side.

Pupa. — The pupa formed from the tomato-worm is buried in the soil and difficult to find. Pupa from cocoons of Cecropia moth, or other large moths, may be used. The cases or covers of various organs, as shown in Fig. 25, may be seen. Identify the covers of the tongue, antennæ, legs, eyes, and wings. Note spiracles on sides of the body. Examine the movable segments of the abdomen.

The fragments to be found in a cocoon at posterior end of a pupa are from the skin which was molted after the cocoon was spun. The larva molts several times before it is full grown and ready to change to pupal stage.

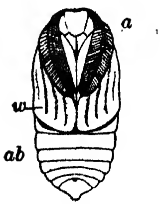

FIG. 25. Pupa of moth. *a*, antenna case; *w*, wing case; tongue and leg cases between antennæ; *ab*, abdomen. (*From Kingsley.*)

Cecropia moths will emerge in February or March if cocoons are kept in a warm room, and much later if left outdoors. The habits of the living moths should be observed. They will live but a short time, for their alimentary canal is too imperfect to use food. This is true only of some of the species of moths and butterflies.

Larva, pupa, and adult stages of common butterflies and moths can be identified by the figures in Dickerson's "Moths and Butterflies," which also gives very readable accounts of the life-histories.

78. Physiology of Insects. — These animals have the following systems of organs: *supporting* (the external skeleton); *muscular* (muscles of the body and appendages); *digestive* (mouth, esophagus, stomach, intestine, digestive glands); *circulatory* (heart and blood-vessels); *respiratory* (air-tubes); *excretory* (some excretions are in the indigestible materials discharged occasionally from the intestine); *nervous* (simple brain in head, a double nerve-cord in ventral part of the body, and nerves extending to various organs of the body); and the *reproductive* organs (ovaries and oviducts in female, spermaries and sperm-ducts in male).

The supporting of the body of the backboned animals is accomplished by an internal skeleton, while an external case or skeleton serves the same purpose in an insect.

The digestive organs prepare food for absorption.

Circulating blood carries digested food, oxygen, and excretions; and a heart provides the motive force of circulation.

The air-tubes of an insect perform the same work as the lungs of the human body.

The nervous system controls the activities of all organs.

The reproductive organs — the ovaries form ova or egg-cells, the spermaries produce sperm-cells, while the oviducts and sperm-ducts are simply tubes for conducting egg-cells and sperm-cells to the exterior, where each egg-cell may be entered and fertilized by a sperm-cell and then develop into a new individual.

79. Molting of an Insect. — It is evident that an animal inclosed in a hard external skeleton cannot grow rapidly while surrounded by such a coat-of-mail. This difficulty is overcome by periodical shedding of the skeleton, followed by rapid increase in size for a short time while the skin remains soft and extensible. The shedding or molting occurs nine or ten times before the grasshopper is full grown. The process of molting is briefly as follows: The skeleton splits along the middle of the back, and through the split the head first emerges and then the posterior end of the body. The struggles to get free from the old skeleton are often so violent that the animal becomes exhausted and dies. The wings are larger after each molting.

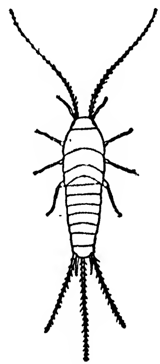

FIG. 26. A "silver-moth," Lepisma. A modern representative of the ancient primitive insects which had three pairs of legs but no wings.

80. Life-Histories of Insects. — The eggs of the simplest and lowest insects (*e.g.*, the silver-moth, Fig. 26) form young which at hatching are like the adults except in size. The young of grasshoppers and of numerous other species of insects are at first without wings, and they go through a number of moltings of the external skeleton before

they become adults. This condition is called *gradual metamorphosis*, or incomplete metamorphosis. The most complicated development is represented by the butterflies, moths, beetles, flies, bees, and wasps. The eggs of these hatch into worm-like *larvæ* (popularly called caterpillars, grubs, maggots). These larvæ are voracious feeders, and usually grow rapidly to full size. Then while transforming from the larva to the adult or *imago* stage, they undergo a period of quiet in the *pupa* stage. The pupa stage of the butterfly is often called a chrysalis. The larvæ of some insects (*e.g.*, silkworm and many moths) spin a protective *cocoon* around themselves as they pass into the pupa stage. After a period of quiet, during which vast internal changes (*complete metamorphosis*) are taking place, the pupal case bursts and the perfect insect emerges in full-grown state.

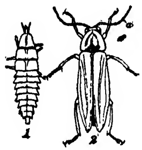

FIG. 27. Firefly larva (*1*) and adult (*2*). Really a fire-beetle, for it is not closely related to flies. (*From Packard.*)

Many insects live longer in the larval than in the adult stage. Some of the May-flies (also called day-flies and ephemerids) live a year in the larval stage and only a day or two as perfect insects. Vast numbers emerge in the morning, soon lay their eggs, are unable to take food, and perish before the next day. The seventeen-year cicadas (erroneously called "locusts," for this name belongs to grasshoppers) spend the greater part of the seventeen years as larvæ

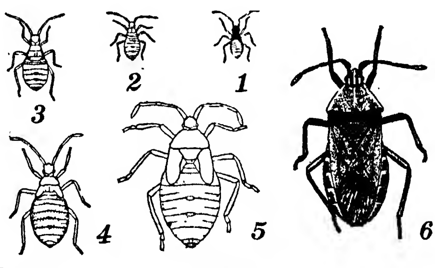

FIG. 28. Stages in the gradual metamorphosis of squash-bug. (*From Folsom.*)

attached to roots of trees. In the seventeenth summer they come to the surface, soon pass through the pupal stage, and then emerge as perfect insects. A few of them may remain for a number of weeks, but vast numbers lay their eggs in the twigs of trees and die within a few days after becoming adult insects. The larvæ, which hatch from the eggs deposited in the twigs, fall to the ground, burrow, and remain in the soil for nearly seventeen years. A thirteen-year variety occurs in the Southern States.

The insects which have complete metamorphosis are regarded as the highest. The complicated life-history has many advantages. The insect in the larval stage is often able to conceal itself and to reach food which perfect insects could not get; for example, the larvæ of numerous species of beetles, of the cicadas, and of flies. In many cases it is possible for the adult insect to supply food for the larvæ; for example, bees supply food to the larvæ in the honeycomb, ants feed and care for their larvæ, some wasps paralyze other insects by stinging and then place them as food for wasp larvæ, and the eggs of many parasitic species are laid in other insects. Still another advantage to some insects is the fact that their larvæ easily withstand the winter storms (examples are many moths with cocoons). Also, there is an advantage in that the larvæ live under conditions different from the adult insect; for example, numerous larvæ feed on foliage which the adults never frequent except for laying eggs.

81. Classification of Insects. — The insects constitute a subdivision of the animal kingdom known as Insecta and this is divided into about twenty groups called *orders*.

In classifying insects, as all other animals, it is necessary to consider all points of external and internal structure in order to determine which kinds or species are most alike;

but it is a fortunate fact that it is often possible to identify many species by means of some one prominent structure. In many insects, the wings happen to be the convenient parts for general classification; but similar wings must not be taken as indicating close relationship if other organs are not homologous (*i.e.*, of corresponding structure).

The most common insects in the United States are conveniently grouped in the following orders: * —

Aptera. — Name means without wings. Example: the "silver-moth" or "silver-fish" (Fig. 136) and the "spring-tails." These are the oldest insects now living. They are primitively wingless; that is, there is no evidence that their ancestors had wings. Fleas are secondarily wingless, because of degeneracy caused by parasitism. Entomologists conclude that the ancestors of fleas had wings because embryo fleas show the beginning of wings. Hence, such degenerate insects are not apterans, but belong in a higher order.

Orthoptera. — Name means straight wings, referring to main veins of the wings, or to the way they fold together. Examples: grasshoppers, crickets, katydids, stick-insects, cockroaches, mantis, earwig. Two pairs of wings, similar to those of grasshopper. Mouth-parts for biting. At least 10,000 species are known.

Netted-winged Insects. — Old books recognize an order Neuroptera for all insects which have two pairs of netted-veined wings like the dragon-fly and May-fly; but study of their other organs and especially of their embryonic development has shown that dragon-flies, May-flies, termites (often called white ants), and others with netted wings are not similar except in their wings. The netted-veined wings are found on insects now grouped in five or six orders. How-

* These are easily learned by examining and comparing specimens.

ever, the beginner cannot do better than to use the popular name "netted-veined," and for further information consult the larger books on insects for descriptions of Neuroptera and other orders of insects which exhibit this kind of wings.

Hemiptera. — Name means half wings, referring to the fact that in some of these insects about half the wing next to the body does not show distinct veins. Examples: all true bugs, cicadas, squash-bug, box-elderbug, "stink-bug," chinch bug, parasitic lice, bed-bug, water-bug, cochineal bug, plant-lice, scale-bugs. Four wings, overlapping when folded. Mouth-parts for piercing. Incomplete metamorphosis. More than 20,000 species.

Lepidoptera. — Name means scale-wings, referring to overlapping scales. Examples: butterflies and moths. Two pairs of wings, covered with flat or hair-like scales. Mouth-parts for sucking. Complete metamorphosis. Butterflies usually fly in daytime and have slender antennæ with knob or club at end. Moths are nocturnal and have feather-like antennæ. Over 50,000 species of Lepidoptera are known.

Coleoptera. — Name means sheath wing, referring to the hard anterior wings. Examples: all beetles, — weevils, fire-flies, June beetles, blister beetles ("Spanish flies"). Some so-called bugs, *e.g.*, lady-bird "bug" and June "bug," are beetles and not bugs (*i.e.*, not Hemiptera). Front wings of beetles are hard and horny, and often called the elytra. Hind wings are membranous. Complete metamorphosis. It is estimated that over 100,000 species of beetles have been named.

Diptera. — Name means two wings; hind wings absent. Examples: flies, bot-flies, warble-flies, mosquitoes. Mouth-parts for sucking (as in house-fly) or piercing (as in horse-flies). Complete metamorphosis. Larvæ commonly called

"maggots." Small knobs represent the hind wings. More than 40,000 species are named.

Fleas. — Parasitic insects, wingless or with rudimentary wings. Formerly considered wingless flies, but now in a special order.

Hymenoptera. — Name means membrane wing, *e.g.*, a bee's delicate wing. Examples: ants, bees, wasps, ichneumons. Mouth-parts for both biting and sucking. Complete metamorphosis. Four wings, hind pair smaller, few irregular veins. Probably about 30,000 species known.

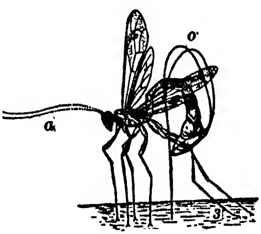

FIG. 29. An ichneumon. *a*, antennæ; *o*, ovipositor; *3*, third legs. (*After Riley.*)

Practice in Classification of Insects. — (*L*) Students should examine a set of insects (a mixed lot preserved in wood alcohol or formalin is best); and by comparing with above descriptions, and the well-known examples mentioned, assign the specimens to the proper orders. In an hour of time one can learn to identify as to orders the most common insects. The names of genera and species of the very common insects can be found in the large books, such as Comstock's "Manual of Insects," but rarer specimens can only be identified by specialists.

Students who are specially interested should read some of these books: Dickerson's "Moths and Butterflies," Comstock's "Insect Life" and "How to Know the Butterflies," Sanderson and Jackson's "Elementary Entomology," Smith's "Insect Friends and Enemies." Kellogg's "American Insects," Holland's "Butterfly Book" and "Moth Book," and Folsom's "Entomology" are more advanced, but even beginners can use their illustrations.

82. Economic Relations of Insects. — Many species of insects are of interest because they have economic or practical relations to man. Many species destroy cultivated plants (see § 320). A very few species, such as the honey-

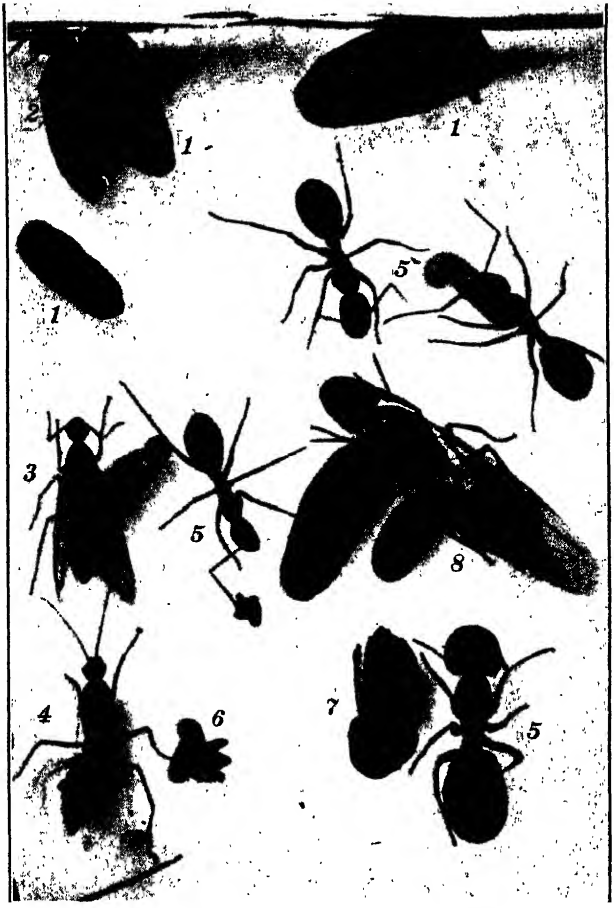

FIG. 30. Photograph of stages in life-history of ants reared in captivity by Adele M. Fielde. *1*, cocoons; *2*, young ant emerging from cocoon; *3*, *4*, males; *5*, workers; *6*, several larvæ; *7*, naked pupa; *8*, winged "queen." (*From Nature-Study Review*, 1905.)

bee and silk-worm, are useful for their products (§ 319). Many species transmit the germs of destructive diseases to domesticated animals. Flies and mosquitoes introduce into the human body the germs of typhoid, malaria, and other diseases (see §§ 260–262).

FIG. 31. Water-boatman. Third legs adapted as oars.

83. Adaptations of Insects. — No other group of animals is so favorable as the insects for study of adaptations of structures to special uses.

Insect legs are adapted to running (cockroach), leaping (grasshopper), walking (fly), grasping (mantis), burrowing (mole-cricket), clinging (moths and butterflies), carrying pollen (bees), and to still other special uses. However, in all these cases the general plan of a leg is similar.

The mouth-parts are adapted to various kinds of foods; biting and chewing (grasshopper, beetles), piercing (mosquito, hemipterans, and some flies), licking (house-fly), sucking (butterflies), and cutting (carpenter-bee).

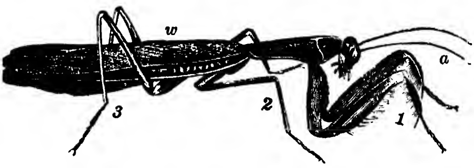

FIG. 32. Mantis. First legs are adapted for catching other insects.

The wings are commonly well adapted to flying, but in some species (*e.g.*, fleas) wings would be worse than useless organs and have become degenerate. The front wings of beetles are thickened to form shield-like covers for the posterior wings. In protective adaptation of some insects the wings are remarkably leaf-like in appearance.

The form of insect bodies is strikingly modified in many

species. Stick-insects (Phasmidæ) are orthopterans in which the body and legs are stick-like and easily mistaken for sticks, twigs, straws, etc., near which these insects live.

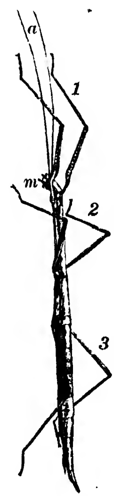

FIG. 33. A stick-insect. *a*, antennæ; *m*, mouth; *1*, *2*, *3*, three pairs of legs.

Some of the most remarkable adaptations are connected with the larval stages. Larvæ of May-flies and others live in water and breathe by means of feathery gills on the abdomen (Fig. 34). The larvæ of mosquitoes have special breathing tubes which can be extended above the surface of the water. Larvæ of lepidoptera which crawl on plants have false legs for supporting the posterior end of the body; but those of flies, beetles, ants, bees, etc., develop in situations where such extra legs are not required and they have only the three pairs of thoracic legs.

FIG. 34. Larva of May-fly, with feathery gills along side of the abdomen adapting to aquatic larval life.

In various ways protective structures for larvæ are formed, and organs are specially adapted for such work. Examples are: spinning silky cocoons (by moth larvæ), making honeycomb (by adult bees), making paper (by adult wasps), making cases or tubes from bits of plants or gravel (by caddis larvæ), and rolling leaves to form tubes (by many larvæ).

Aquatic insects are especially noteworthy for their adaptations. In some species oar-like legs are fitted for locomotion by swimming. Mosquito larvæ propel themselves by "wriggling" of the abdo-

men. Some aquatic larvæ (*e.g.*, mosquito pupæ) are so filled with air that they float at the surface and can descend only by swimming. A velvety covering of hairs on the body and legs enables some insects to skate on the surface film of water. The silvery white of the "backswimmers" is due to a layer of air held by delicate hairs. Other aquatic beetles and bugs have air-spaces beneath the front wings.

Adaptations of insects with respect to color are so important that a separate section of this chapter is devoted to them.

84. Colors of Insects. — Many insects are colored in ways which are apparently useful to them. Such useful colors are commonly interpreted as (1) protective, (2) aggressive, (3) warning, (4) mimicry.

(1) *Protective coloration* is the most common form of useful colors among insects. A green insect on a green leaf is more or less concealed because it so closely resembles its surroundings. Many insects resemble the bark of trees on which they rest, and some both in form and color resemble sticks and leaves. In still other ways numerous insects resemble the objects near which they habitually live. Such similarity to the environment is believed to be protective against enemies. Note that it is not absolutely protective, for such insects are often captured by birds; but probably more such insects escape than would if they were not protectively colored.

(2) *Aggressive coloration* is the term applied to insects which resemble their environment so that they can lie concealed from their approaching prey. This is found in certain predaceous insects like the mantis, which at the same time are protectively concealed from such enemies as birds.

(3) *Warning Coloration.* — Many insects are conspicuously colored, and appear to make no attempt at hiding them-

selves. The common monarch butterfly is an example. The explanation is that such insects often have a disagreeable odor, flavor, or sting which repels their enemies; and hence the conspicuous color is a danger signal.

It has been learned by experiments that insect-eating monkeys soon learn that such a conspicuous coloration is associated with disagreeable things and thereafter will not attempt to catch such insects. This suggests that a species with warning colors would have an advantage in that the comparatively few individuals caught might teach the enemy that such brightly colored insects are not good to eat.

(4) *Mimicry.* — This means the resemblance of one species of insect to another which has warning colors. The American viceroy butterfly is a mimic of the monarch. Young insect-eating monkeys will eat viceroy butterflies, but will not touch them if they have first tasted some unpalatable monarchs. This leads to the view that the viceroy species gains decidedly by resembling and thus living on the bad reputation of the monarch, which has warning colors. In tropical countries there are numerous similar cases where a conspicuous insect which has no special defense against its enemies is similar in appearance to another species whose conspicuous colors are warning signals, advertising boldly to enemies that there is danger.

The word " mimicry " suggests conscious imitation; but, of course, one insect resembles another because it happened to be developed that way. We do not know how the first viceroys came to resemble monarch butterflies, but probably a butterfly appeared which was unlike its near relatives and more like monarchs. This resemblance to the monarchs gave the first viceroy an advantage. Other viceroys developed because " like tends to produce like," which principle of embryology applies especially to the propagation of

individual organisms born with some peculiarity. Obviously, any slight advantage gained by the resemblance to the monarchs, which are not so liable to attack as are more edible insects, would have tended towards the continued multiplication of viceroys. It is thus easy to suggest how viceroys might have been preserved and allowed to multiply; but it has not yet been discovered why the first viceroy happened to be so unlike its relatives.

The above explanation of insect colors as protective, aggressive, warning, and mimicking is believed to apply to many insects. It should be understood that these devices for the use of colors are not absolutely perfect in their working. For example, green grasshoppers concealed in green leaves are often discovered by birds; but there is reason to believe that the green color makes it harder for birds to find the insects, and hence the color gives some protective advantage. Likewise, warning colors are not always efficient danger signals; and mimicry does not always deceive enemies. However, there is probably a decided advantage, on the whole, to species of insects which possess any of these forms of coloration.

85. Colors of Other Animals. — Animals other than insects may have useful coloration. Thus fishes, frogs, lizards, and many other animals may have concealing coloration which may work either protectively or aggressively. The white of birds, hares, and other small animals on arctic snowfields is believed to be protective; while the white of polar bears may be aggressive, enabling them to lie in wait for the approach of prey. The stripes of tigers are supposed to be aggressive because they harmonize so well with the lights and shadows among the reeds of jungles. Likewise, the tawny color of the lion resembles the sands of the desert.

Some of the most remarkable cases are those of frogs

and lizards, which can quickly change colors when placed on new objects, *e.g.*, from green to brown when moved from a leaf to the bark of a tree. This is accomplished by a peculiar arrangement of pigment-cells in the skin. Some cells contain green pigment and some have darker colors. When the green cells are expanded so as to expose their maximum surface, and the dark cells are contracted, the animal's skin appears green. Expanded dark cells and contracted green cells make the skin brown in color. Partial expansion and contraction of both kinds of pigment-cells give intermediate shades. The cells are controlled through the nervous system and the eyes.

In the case of those birds and mammals which appear to have concealing colors, it should be remembered that many of the enemies have a keen sense of smell, and so colors cannot always be useful. For illustration, quails and other birds which live on the ground are more or less protectively colored. This may help them some in escaping such enemies as hawks, but obviously would be of no protection against weasels, skunks, and other enemies which hunt by night, guided by odors and not by colors.

Finally, it should be noted that some colors of animals are probably not useful. For examples, we may mention the beautiful colors concealed in shells of some kinds of mollusks, the "eye-spots" in wings of some moths and butterflies, and the gorgeous color-patterns of many birds (*e.g.*, peacock). For all of these and very many more we have as yet no satisfactory explanations.

86. Instincts of Insects. — The instincts of insects have long aroused the wonder of students of animal life, for under the guidance of inherited instincts many insects exhibit remarkable behavior. It is instinct which leads honey-bees to build honeycomb, care for the young in true nurse fashion,

give a different kind of food to the larvæ destined to become "queens," follow the "queen" when she leaves the hive at swarming time, sting intruders, and in various other ways behave almost like intelligent beings. It is instinct which leads parasitic species to lay their eggs in the right kind of larvæ, and other species to place the eggs on plants which will furnish the right kind of food for the young larvæ. It is instinct which leads certain wasps to capture and paralyze other insects, and then place them where wasp larvæ hatching from eggs can eat them later. In short, thousands of cases of striking behavior of insects are apparently due to instinct. Some of the actions of insects suggest that they are intelligent and capable of reasoning; but the most critical studies have led entomologists to the conclusion that insects do not reason, but that they constantly act instinctively and automatically. How they originally acquired their instincts is entirely unknown, but that the instincts are transmitted from generation to generation is certain. A bee does not have to learn to build honeycomb, for to do this is as natural as eating and moving. It is an instinctive action.

Some insects seem to have ways of communicating with each other. An ant or bee may, while wandering around, find something good to eat, and soon many others will follow the first one from the nest. This is probably due to the odor of food conveyed to the nest by the first insect. The ability of ants to recognize those from another nest is merely distinguishing between odors of different nests.

87. Classification, or Position of Insects among Animals. — The animal kingdom is composed of various types of animals. The highest and most complex in structure are the backboned animals or *vertebrates,* so named because the backbone is a series or a row of bones, each of which is called

a *vertebra.* Common types of vertebrates are fishes, frogs, reptiles, birds, and mammals (dog, horse, sheep, seal, monkey, etc.). Simpler in structure and therefore lower than the vertebrates are the backboneless animals (*invertebrates*), examples of which are: mollusks (clam, snail, oyster), insects, crustaceans (crayfish, lobster, crabs, shrimps), worms, jelly-fishes, sponge-animals, and the simple animals revealed by the microscope. The insects are among the highest of the backboneless animals. They are similar to spiders and to crustaceans, especially in having an external skeleton and legs with many joints; and because of similarity the insects, spiders, and crustaceans are placed together in a great group known as the *arthropods* (scientific name, Arthropoda).

Chief Groups of Animals and Plants. — In the table below the lowest group of the animals is named first and the highest last, but there is doubt as to the relative position of some of the intermediate groups; for example, whether annelids are higher than echinoderms, or arthropods higher than mollusks. Each of these primary groups of animals is usually called a *phylum* (plural *phyla*), *e.g.*, Phylum Protozoa. The advanced textbooks of zoölogy include about fifteen phyla of animals. The common animals belong in the ten phyla named below. The main subdivisions of these phyla are given at the ends of the chapters in Part III of the "Applied Biology."

Protozoa (simplest, one-celled animals).
Porifera (sponge-animals).
Cœlenterata (hydroids, jellyfishes, coral-animals).
Platyhelminthes (flat worms, tapeworms).
Nemathelminthes (round worms).
Annelida (segmented worms).
Echinoderma (starfish, sea-urchin, crinoid, sea-cucumber).
Arthropoda (lobster, crab, spider, centipede, insect).
Mollusca (clam, oyster, snail, cuttle-fish).
Vertebrata (backboned animals).

CHAPTER VI

SOME ANIMAL STUDIES PRELIMINARY TO HUMAN BIOLOGY: VERTEBRATES

The purpose of this chapter, and of the two that follow it, is to teach the chief facts regarding the structure and functions of some animals which help us to an understanding of the biological study of the human body in Chapter VIII. Study of any animal or plant is helpful in preparation for study of the human body; but the vertebrate animals are especially helpful because in their general structure and functions they are very much like the human body. For this reason, the present chapter is devoted to certain vertebrates. The next chapter deals with certain lower animals which illustrate more simply than do the vertebrates principles of biology that apply to the human body. Finally, in Chapter VIII the human body will be considered in the light of the studies of animals in Chapters VI and VII, and of plant physiology in Chapter IV.

Among the backboned animals none has been so popular for scientific study as the common frog. Many books, some of them very large, have been written about the biology of this animal, and the scientific knowledge concerning it is greater than that on any other animal. Strange as it may seem, we know far less concerning the human body from direct study; but fortunately the frog and the human are so much alike in numerous ways that biologists have applied to the human species many facts which were learned first

by study of the frog. Since the study of the frog by scientific men has played so important a part in building up the science of animal biology, teachers now regard this animal as valuable for study by those who wish to rediscover for themselves some of the most important facts concerning animal structure and life.*

Readers of this book who have not studied, in elementary school nature-study, the life of the common toads and frogs should read at least one of the following: "Usefulness of the American Toad," in Farmers' Bulletin, No. 196 (free from U. S. Dept. of Agriculture); "Life History of the Toad," in Cornell Nature-Study Leaflets; or Chapter 16 in Hodge's "Nature-Study and Life."

I. THE STRUCTURE (ANATOMY) OF THE FROG OR TOAD†

88. External Structure of the Frog. — (*L*) Place a living frog in a clear glass tumbler, and cover with paper or mosquito-netting. The ordinary "jelly-glasses" with tin covers are convenient, if small holes are punched in the cover. By looking through the glass, it will be possible to learn many things about the frog's external structure and habits.

Notice that the frog's body consists of head, trunk, and limbs. How many limbs? Is there a neck, or a tail?

Imagine your own body supported on all four limbs (*i.e.*, walking on hands and feet) and locate anterior, posterior, dorsal, and ventral.

* To TEACHERS: Before beginning any dissection of animals, it will be helpful to give the students the point of view of § 34, "Justifiable Use of Animals for Science Study," in the "Applied Biology."

† To TEACHERS: Concerning the importance of demonstrating the structure of either frog or toad, in case individual work by students is impossible, see § 35 in the "Teachers' Manual of Biology."

Some teachers may prefer the crayfish for beginning dissection (see § 310 in the "Teachers' Manual of Biology"). For such work there are laboratory directions in § 310 of the "Applied Biology," and mimeographed copies could easily be made for use of students.

Make an outline sketch of the frog as seen in profile and another one of a boy as you imagine him walking on hands and knees, and then write the four terms given above on your sketches so as to indicate the parts of the body to which they are applied. Compare the right and left sides of the frog. Remember that in the study of animal biology right and left refer to the frog's body, not to your own. Hold the tumbler so that the frog will sit with its head pointed away from you, and your right will be the frog's right. If the animal were lying on its back with head pointed away from you, as you look down upon its ventral surface, would your right be right or left of the frog? Are the two sides of the frog's body alike? Are the right and left sides of your own body similar externally?

At this point it will be well to have at hand a dead frog, one either recently chloroformed or preserved for some time in formalin. Examine the dead frog for all points not easily seen in the living one kept in the glass tumbler.

Skin. — Note the color of the skin on the dorsal surface of the frog's body. Compare with the color on the ventral surface. In a later chapter it will be pointed out that many zoölogists think that these colors help to conceal the frog in the grass along ponds, among water weeds, and in other places where frogs live. When you make a trip into the country look for evidence that the color helps to conceal the frog. The skin is covered with a slime or mucus. How would this help the animal if an enemy tried to catch it?

Are there hairs on the frog's skin? Look with a hand-lens. Compare with your own skin.

Sense-Organs. — (*a*) Examine *eyes*. Are there eyelids? Can the frog close its eyes? Look into a small mirror and compare your own eyes with those of a frog. (*b*) *Ears* — the large, dark round spots just behind the eyes are the membranes of the ears, stretched like a drum-head over the cavities (internal ears), which will be examined later. The frog has no projecting external ears such as the human being has. Also in the human ear the ear-drum (tympanum) cannot be seen from the outside, because it lies deep in a canal or tube which leads to the internal ear.

Limbs. — Compare the anterior limbs with the posterior ones. Are they alike? In the anterior limbs (fore legs) notice three divisions: upper arm, extending from shoulder to elbow; forearm, extending from elbow to wrist; and the "hand." How many "fingers"? Compare the anterior limb with your own; *i.e.*, your

arm. What differences in the divisions do you notice? What similarities? In the posterior leg (hind limb or hind leg) of the frog notice: the thick fleshy thigh, extending from the hip to the knee; the shank, extending from knee to ankle; and the foot. How many toes? Compare with number of "fingers." The shortest toe corresponds to the big toe of the human foot.

Notice the membrane ("web") stretched between the toes of the hind foot, fitting the foot as a paddle for swimming. When you have an opportunity to observe frogs swimming in a large aquarium, or in the clear water of a pond, compare the uses of fore and hind limbs. The fitting of any structure or organ of an animal or plant to a special function is known as *adaptation*. Another adaptation of the frog's hind legs is in the great muscles of the thigh, which fit it for jumping.

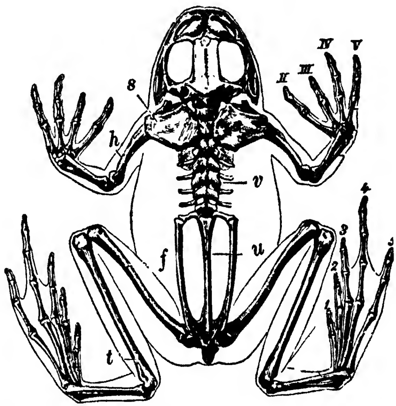

FIG. 35. Skeleton of frog. *f*, femur; *h*, humerus; *s*, scapula; *t*, tibia; *u*, urostyle (end of backbone); *v*, vertebræ.

Mouth. — The opening is the mouth, and inside is the *mouth-cavity* (also called buccal cavity, meaning cheek cavity). Commonly we speak of the human mouth-cavity as mouth, and the opening as lips; but to be accurate "mouth" should be applied to the opening. Examine the mouth-cavity of a frog that has been chloroformed. Are there teeth? Look for teeth on a mounted skeleton of a frog. Notice two small openings (*nostrils*) on the dorsal side of the head near the upper lip of the frog's mouth. Pass a shoemaker's bristle or a slender broom-straw into a nostril, and note where the bristle comes out into the mouth-cavity. The human nostrils have no such direct communication with the mouth-cavity. With a needle make a hole in the frog's ear-membrane back of the eyes, and then carefully push a bristle into the opening. Open the mouth and find where the bristle comes out into the mouth-cavity.

To prove a similar connection between the human ear and the back part of the mouth-cavity, close your nostrils with your hand, then swallow once or twice and notice a feeling of pressure in your ears, due to forcing air back into the middle part of the ears. This explains why workmen are told to swallow air when entering the compressed air chambers used in tunneling under rivers. The tubes connecting the middle parts of the ears with the mouth are known as *Eustachian tubes*, named in honor of Eustachius, professor of anatomy at Rome, who published a description of the human ear in 1754.

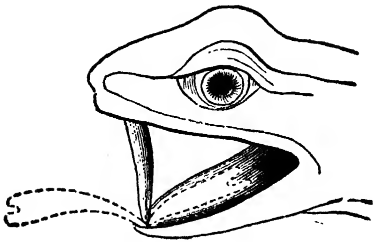

FIG. 36. Various positions taken by tongue of frog when catching an insect. (*After Wiedersheim.*)

Examine the frog's *tongue*, and note that it is attached at the forward end to the tip of the lower jaw, while the free end extends backward towards the throat. How does this compare with the human tongue? In seizing an insect, the frog's tongue is turned quickly forward out of the mouth, and then quickly withdrawn. (See Fig. 36.)

89. Internal Structure of the Frog. — (Chiefly *D*) Look at the mounted skeleton of a frog, compare with Fig. 35, and note the position of the following bones: backbone (vertebral column); skull; shoulder-girdle, which is a set of bones attaching the fore legs to the body; pelvis, a set of bones which attach the hind legs to the body. Notice that the "ribs" are very short. Now turn to the frog you have been studying, and feel the position of the above-named bones through the skin.

Lay the frog on its back, head pointing away from you. With forceps lift the skin and with scissors carefully cut through it, along the median ventral line, the whole length of the body. Carefully separate the skin from the underlying parts, cutting the thread-like connections, turn the flaps of skin outward to right and left, and pin to the board or wax in the bottom of a dissecting-pan. Cover the frog with water.

Notice the *muscles* of the body-wall of the abdomen, and the bones connecting the fore limbs (shoulder-girdle).

Again using scissors and forceps, carefully cut through the body-wall in the median ventral line from the pelvis to the shoulder-girdle, and then cut across the body (transversely) just posterior to the girdle. Separate and spread out the two flaps of the body-wall, and pin down to the dissecting-board. The cavity containing the

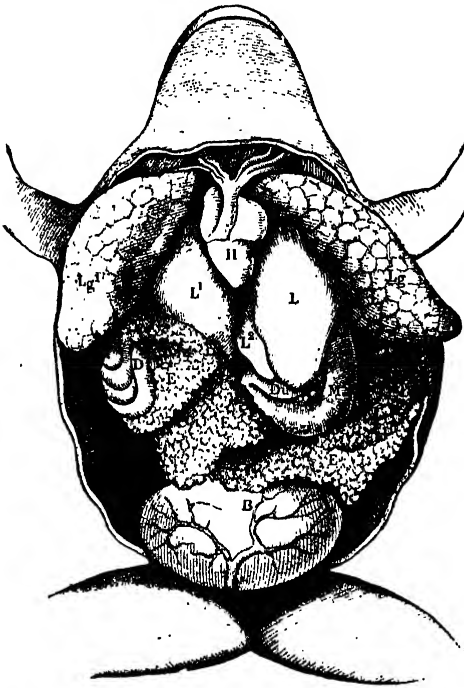

FIG 37. Frog dissected from ventral surface. *H*, heart; *Lg*, lungs; *L*, liver; *M*, stomach; *D*, intestine; *E*, ovaries; *B*, bladder. (*From Ecker.*)

internal organs thus opened is the *body-cavity* (cœlome). Now identify the organs exposed — liver, stomach, intestine, egg-organs or ovaries (if the specimen is a female frog), comparing your specimen with Fig. 37 in order to identify the organs.

Now cut out, with strong scissors, the ventral bones of the shoulder-girdle (the teacher will demonstrate how this is best done).

As you lift up the bones, notice the *heart* lying beneath. The posterior, conical, whitish part of the frog's heart is called *ventricle* (Fig. 37); it lies in a depression between two parts of the liver. Anterior to the ventricle are the thin-walled *auricles* (right and left), usually found filled with dark blood in a dead frog. The ventricle is the part of the heart which forces the blood from the heart into the blood-tubes (blood-vessels); while the auricles are reservoirs for holding blood coming back to the heart and collecting for the next " beat " of the ventricle. The extremely thin membrane which incloses the heart is the *pericardium* (meaning, around the heart).

(*D* or *L*) At the anterior end of the heart is a blood-tube (aorta) which branches into two smaller tubes, each of which has several smaller branches leading to the right and left * sides of the body. These are the chief blood-tubes through which blood flows away *from* the heart, and they are called *arteries.* The branches of the two arteries lead to all parts of the body, and may be seen in many organs. Connecting with the anterior end of the heart and on its dorsal surface are three thin-walled tubes, which, in dead frogs, are usually filled with dark purple blood. These are the blood-tubes in which blood flows back *to* the heart, and they are called *veins.* Later we shall see small branches of the three veins in various parts of the body. In fact every organ which has an artery in which blood comes from the heart must have a vein for the return of blood to the heart; for the blood circulates from heart to arteries, from arteries to smaller tubes called *capillaries*, from these to veins, and thence back to the heart.

(*D*) *Capillaries.* — Watch the flowing of blood through the capillaries in the tail of a small tadpole allowed to lie on its side on a wet plate of glass, or in the spread web of a frog's foot. Use low power of microscope.

In addition to the system of blood-tubes carrying blood from the heart, through the capillaries in all organs, and back again to the heart, there are in all organs many small tubes which collect a watery fluid called *lymph.* This is largely derived from the liquid part of the blood, and it ultimately flows back into the blood.

The largest organ in the frog's body is the *liver*, a bi-lobed organ

* The student should remember that with the frog lying on its back the right side of the frog will be on the observer's left. In all descriptions in this book, right and left refer to the animal studied, not to the observer.

lying behind and at the sides of the heart. Its color is reddish brown in frogs not preserved in chemicals.

Ovaries. — In a full-grown female frog, masses of spherical black and white eggs (ova) lie among the other organs (Fig. 37). These ova are attached to, or are really united to form, two organs (the ovaries or egg-organs) which later will be found to be fastened to the dorsal wall of the body-cavity, one on the right and one on the left of the median line; *i.e.*, bilaterally symmetrical. With forceps, pull out the masses of ova, taking care not to injure other structures.

Alimentary Organs. — These are the organs concerned with receiving food and preparing it for the use of the frog's body. The *alimentary canal*, or *food-tube*, extends through the body from the anterior to the posterior extremity (Fig. 38). The *mouth* is the anterior opening; the posterior opening is called *anus*. Turning the organs in the body-cavity, but not cutting, examine the various parts — stomach, intestine, etc. — of the food-tube. The stomach lies dorsal to the left lobe of the liver. The short tube from stomach to throat is the *esophagus* (gullet). The throat or *pharynx* connects the esophagus with the mouth-cavity. Carefully push a probe (such as a small stick) down the throat into the stomach. The tube extending from the stomach backwards or posteriorly is the *intestine*. Note that the first part lies parallel to the stomach. The constriction between the stomach and this first part of the intestine is the *pylorus*. The small intestine is a slender and much convoluted tube. The large intestine (or rectum) is a short, straight tube, of greater diameter than the small intestine. The expanded end of the large intestine is called *cloaca*. Tubes from the kidneys and reproductive organs open into

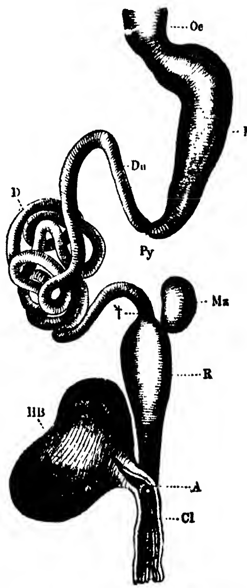

FIG. 38. Alimentary canal of frog. *Oc*, esophagus; *M*, stomach; *Du*, *D*, small intestine; *Py*, pylorus; *Mz*, spleen; *R*, large intestine; *HB*, bladder; *Cl*, cloaca. (*From Ecker.*)

the cloaca; but this is not so in the highest animals. The opening of the large intestine to the exterior is on the dorsal surface of the body near the end of the backbone. In all animals this opening is called *anus*.

Carefully cut the membrane (*mesentery*) which holds the alimentary canal in place, cutting close along the canal, and pin the intestine to one side and out of the body-cavity. Cut open the stomach longitudinally. It may contain food, such as softened and disintegrated pieces of worms, etc.; the condition of the food suggests that solid foods are dissolved in the stomach. Wash out the contents, and notice the longitudinal folds which line the stomach and increase the surface with which food comes into contact. Cut open the intestine in several places. Do you find folds arranged as in the stomach? Notice that the food in the intestine is more liquid than the food in the stomach. Also notice that by the time food has passed along the posterior part of the intestine its bulk has been greatly reduced — the stomach's capacity is much greater than that of the intestine. Evidently the greater part of the food disappears as it passes along the stomach and intestine. Where does it go?

In addition to the parts of the food-tube, the *liver* and the *pancreas* must be considered alimentary organs, because they form or secrete substances needed for preparing foods in the intestine.

The liver, whose position has been noticed, consists of two lobes, the lobe on the left side of the body being larger and subdivided into two parts. Notice a small sac, the *gall-bladder*, between the right and left lobes. The greenish-colored fluid which fills the gall-bladder is the *bile*, which is made by the liver and stored in the gall-bladder until it is needed in the intestine. A bile-duct (very small and difficult to see) leads from the gall-bladder to the intestine.

(*D*) The pancreas lies between the stomach and intestine. It is an irregularly lobed mass of light color in fresh specimens. It secretes a fluid (*pancreatic juice*) used in digestion of foods. Many of its small ducts open into the bile-duct, which extends along the pancreas on the way from the gall-bladder to the intestine.

Cut the attachment of the liver, esophagus, and intestine and remove these organs, thus exposing other organs nearer the dorsal part of the body-cavity.

(*D*) The *lungs* are two thin-walled sacs, which, before removal of the liver, were dorsal to that organ. Cut through the articulation of the jaws so as to allow the mouth to open widely, and demonstrate

the slit-like *glottis* in the pharynx just ventral to the opening of the esophagus. The tube into which the glottis opens is the windpipe or *trachea*, which has two branches leading to the lungs. Insert the end of a small tube (blow-pipe) into the glottis and blow in air to inflate the lungs, or, using a rubber-bulbed pipette, fill them with water.

(*L*) Watch a living frog in a glass jar, and observe how the floor of the mouth ("throat") moves up and down at regular intervals. Count the movements in one minute. The frog cannot breathe as we do but practically "swallows" air, forcing it down into the lungs by moving the floor of the mouth up while the mouth and nostrils are closed. Many persons breathe while keeping the mouth open, but a frog cannot breathe when the mouth is held open. Not every movement of the throat forces air down into the lungs; most of the movements simply pump air into and out of the mouth-cavity through the nostrils. But watch carefully, and occasionally the sides (flanks) of the body back of the shoulders will be seen to expand greatly when the frog seems to take a big "swallow" of air; this expansion indicates that air has been forced down into the lungs. Then, after a time, the muscular walls of the body help the elastic lungs expel the air, forcing it up into the mouth-cavity, where it is gradually mixed with fresh air pumped in through the nostrils.

(*D*) The *kidneys* are flat bodies of a dark-red color. They are attached to the dorsal body-wall in the posterior portion of the body-cavity, one on each side of the backbone. The *ureters* are the ducts or tubes of the kidneys which lead to the terminal part of the large intestine (*cloaca*); they are very small and difficult to demonstrate. The kidneys extract water and certain other substances from the blood which flows through them, and then pass these substances to the exterior through the ureters and cloaca. Before these substances from the kidneys are eliminated, they may be stored for a time in a sac known as the *bladder*, which lies on the ventral side of the cloaca, and opens into it. This structure is usually found as a collapsed membrane if one looks carefully before cutting out the large intestine.

The *spleen* is a small, oval, red body attached to the mesentery near the large intestine.

Reproductive Organs. — (*D* or *L*) Examine these organs in specimens of each sex. In the male frog the *spermaries* are a pair of yellow

ovoid bodies attached ventrally to the kidneys. Their ducts lead into the kidneys, and there connect with little tubes leading to the ureters, and thence through the cloaca to the exterior. These organs produce *sperm-cells* which fertilize *ova* or *egg-cells*, as described later, in Chapter XII.

In the female, the *ovaries* are attached at about the same place. The *oviducts* are a pair of long, much-coiled, white-colored tubes, lying close to the dorsal wall of the body-cavity and at the sides of the kidneys. Posteriorly they open into the terminal part (cloaca) of the intestine, while anteriorly they have funnel-shaped openings into the body-cavity dorsal to the liver. There is no direct connection between the ovary and the oviduct, but the ova, when mature, fall into the body-cavity, pass through the above-mentioned openings into the oviducts, and then to the exterior through the cloaca. (The use of the reproductive organs will be described in Chapter XII.)

The *fat-bodies* are tufts of bright-yellow masses attached to the dorsal side of the body-cavity behind the liver. The fat is food stored for use in the early spring. Such fat-bodies are found only in frogs and their near relatives, but other animals store fat in various organs.

Nervous System. — (*D* or *L*) Remove all the organs which have been studied and cut away the floor of the mouth. Notice (1) the *skull*, which is covered on its ventral surface by the roof of the mouth, and (2) the backbone or *vertebral column*. The skull contains the brain, and the backbone is a tube which incloses the spinal cord. Looking at the body-cavity side (*i.e.*, ventral), notice the large nerves which extend from the vertebral column to the fore and hind limbs; also some small nerves extending out to the body-wall of the back. Examine brains which have been hardened by chemicals and then removed, and also observe a specimen of a frog dissected from the dorsal side to show brain and spinal cord.

Skeleton. — The chief bones of the frog can be identified by comparing a skeleton with Fig. 35.

The *muscles* of the frog's legs should be examined as to their attachments to the bones. Also, note how shortening of muscles would affect the movements of bones to which they are attached. There are other muscles in the body-wall, and in the walls of stomach intestine, and blood-tubes.

90. Organs of Frog. — Summarizing, we have found the frog to be made up of parts or organs as follows: —

Alimentary organs: mouth, mouth-cavity, pharynx, esophagus, stomach, small intestine, large intestine (including cloaca), liver, and pancreas.

Breathing organs: nostrils, mouth-cavity, pharynx, trachea, lungs, and skin.

Circulation organs: heart, arteries, veins, capillaries, lymph-vessels, and spleen.

Excretory organs: kidneys, ureters, bladder, cloaca, lungs, and skin.

Nervous organs: brain, spinal cord, nerves, eye, ear, and nose.

Supporting organs: skeleton (bones and cartilages).

Muscle organs: muscles of body-wall, of limbs (for locomotion), and of internal organs (heart, stomach, etc.).

Reproductive organs: ovaries, spermaries, ducts of ovaries and spermaries, and fat-bodies (peculiar to frog and its relatives or allies).

II. THE TISSUES OF COMPLEX ANIMALS: MICROSCOPIC STRUCTURE

91. Structure of Organs. — The bodies of complex animals, such as insects, crayfish, snails, fishes, and frogs, are composed of many parts which we call organs, examples of which are skin, liver, stomach, heart. We shall now examine more carefully the structure of some organs.

(*D*) Examine a frog's leg. First on the outside, notice the skin. Remove the skin, and the muscles are brought into view. Compare a piece of skin with a piece of muscle. Is there any difference? In separating the skin from the muscle, or the muscles from each other, notice fine but strong threads binding them or connecting them. Notice bright, glistening bands (called *tendons*) which unite muscles

to bones. Next, examine the nerves which lie between the large muscles. Scrape the muscle from the bone and attempt to cut into it about the middle and also at the rounded ends. Is there any difference?

In thus examining the leg of any animal we find that it is composed of several distinct kinds of building materials. These are *tissues*. The surface of the skin is an example of protective tissue which is called *epithelium* or *epithelial tissue*. The strong threads binding skin to muscle, muscles to each other, and (in form of tendons) muscles to bones, is known as *connective tissue*. The muscles contain *muscular tissue*, and the nerves have *nervous tissue*. The hard part of bones is *bony tissue*, and the softer tissue at the ends of bones is called *cartilage*.

(*L*) Examine your own hand. Skin or epithelial tissue covers and protects it. Pull upon the skin, and it is found to be bound (by connective tissue) to the underlying muscles, which you can feel and move. You can also feel bones. Lastly, you have the sense of touch or feeling in the hand; this indicates the presence of nerves. Name the tissues which you find in your hand. Do you find any which were not named above?

The tissues that have just been examined are the kinds of building materials which form not only an animal's legs, but also its whole body. The same kinds are also in our own bodies. If we were to examine any organ in a frog or in the human body, we should find it made up of two or more of the tissues. For example, the heart is largely composed of muscular tissue, but it has nerves, connective tissue, and epithelium; and the stomach has epithelium, muscles, nerves, and connective tissue. Any complex animal's body is made up of many kinds of materials or tissues which have different appearances and serve different purposes. And just as the materials (iron, stone, brick, wood, etc.) used in building houses may be put together in various combinations so as

to form many different kinds of buildings for different purposes, so the few kinds of building materials or tissues of an animal's body are united to form organs which are quite different in appearance and purpose. An animal's heart does not resemble a leg muscle and their purposes and work are different, but they are chiefly composed of the same kind of tissue (muscular), because muscular activity is needed for movement in legs and in the heart. In like manner, we find epithelium wherever there is a surface, inside or outside, to be covered; cartilage wherever flexibility combined with considerable rigidity (*e.g.*, at ends of bones) is needed; connective tissue wherever other tissues must be joined together; bones for supporting framework; and nervous tissue in all places where nervous activity (feeling, sensation, control, etc.) is needed. Each tissue has its peculiar purpose, just as wood, bricks, and iron have their own purposes. Briefly, the purposes or functions of the tissues are as follows: epithelium for covering, connective tissue for uniting, bone for rigid support, cartilage for flexible support, muscular tissue for contraction and movement, and nervous tissue for feeling and control.

So far we have been studying the larger structure of animals as seen by the unaided eye. We have been able to locate the various organs and to learn something about their general form or position; but concerning the structure of the organs themselves our unaided eyes have been able to discover only the tissues. It is now necessary to make use of the microscope in order to see the minute structure of the tissues which we find in organs.

(*L*) If Chapter III has not been studied, a lesson on the use of the compound microscope should be introduced at this point.

92. Cells. — (*D*) Mount a small piece of the outer skin (epithelium) of the frog in a drop of water on a glass slide and cover with

a cover-glass. Examine this with a compound microscope (magnification 50 to 100). The epithelium is seen to be composed of small (usually hexagonal) blocks, called *cells*, set side by side like bricks in a wall or pavement (see Fig. 39). A small spherical mass (called *nucleus*) may be seen near the center of each cell, and in most of the cells the nuclei may be brightly stained by dipping a piece of epithelium into a dye such as eosin solution (red ink), then into water, and then mounting on a glass slide for microscopic examination. In the same slide notice that the cells are closely joined together; in fact, there is between them a cement substance, which can be dissolved with some chemicals, and the cells are then easily separated.

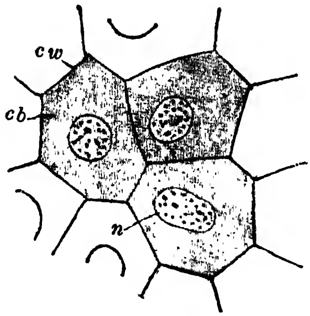

FIG. 39. Diagram of cells from frog's skin. *cw*, cell-wall; *cb*, cell-body; *n*, membrane of nucleus; black spots in nucleus are chromatin. (*From Verworn.*)

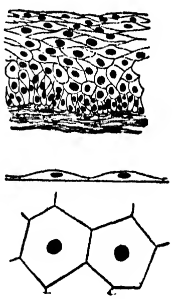

FIG. 40. Upper figure shows that there are many layers of cells in epidermis, those of Fig. 39 being at the surface. The lower diagrams represent two cells in surface and edge views.

Cells. — We have chosen the frog's epithelium as a convenient introduction to *cells*. All other animal and plant tissues which biologists have examined microscopically have been found to have cells; and so the cells are regarded as the units of which the bodies of organisms are composed. Various forms of cells are shown in Figs. 39, 41, 42, 43, and 49. The word *cell* commonly means a cavity, and it was originally applied to certain plant cells (*e.g.*, in cork and elder-pith which have cavities in their substance); but it is now known that most animal

cells and many plant cells do not have cavities. Nevertheless, the word *cell* has become firmly fixed in biological language, and so we must use it as the scientific word for the elements or units of animal or plant tissues. The spherical structure seen near the center of each cell of the frog's skin is the most common form of *nucleus;* but in some cells of other animals the nuclei are in various forms—ribbon-like, like a string of beads, or even scattered in fragments in the substance of the cell. Apparently every living cell has a nucleus of some one of these forms. The substance of a nucleus is called *nuclear material*. Careful experiments have proved that a cell cannot continue to live without a nucleus. Organisms grow by multiplication of cells, and the nucleus plays an important part in that process of cell-division. Notice the similarity of the animal and plant cells in Figs. 46, 47. The boundary of a cell is called *cell-wall* or *cell-membrane;* it is sometimes exceedingly delicate, and sometimes very thick and hard, as in certain plant cells. The substance between the cell-wall and the nucleus is called the *cell-body*. Cells are composed of cell-substance, part of which is living substance and part is stored food and other lifeless materials to be considered later.

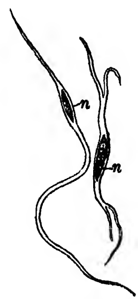

FIG. 41. Unstriated muscle cells. *n*, nucleus.

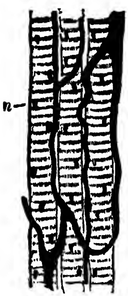

FIG. 42. Parts of three striated muscle cells from a leg, showing many nuclei (*n*) in each cell, and blood-capillaries (black lines) between cells.

93. Inter-cellular Substance. — In some animal tissues all the substance does not lie within cell-walls; some of it

is between cells or *inter-cellular.* In the frog's skin and muscles there is a cement substance between cells which holds them together. This is called *inter-cellular substance,* and is formed or secreted by the cells. In an epithelial tissue, such as the frog's outer skin, there is comparatively little inter-cellular substance. In some tissues there is a large proportion of inter-cellular substance, and an example will now be examined.

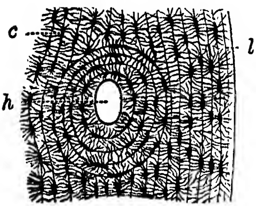

Fig. 43. Section of bone. *c*, cavities containing bone cells; *h*, canal; *l*, layers or lamellæ of bone secreted by bone cells.

(*D*) With a sharp knife or razor cut very thin slices of cartilage or "gristle" from the joint end of a bone procured at a butcher's shop, or from a frog's bone. Mount these slices in a drop of water on a slide. Examine with a microscope. Notice that the greater part of the tissue is a bluish-white substance in which the cells lie. The distance of one cell from another is often more than the diameter of the cells (see Fig. 44). Was this so in the epithelium of the skin? It is evident that the greater bulk of cartilage is not cells, but the substance between the cells (*i.e.*, inter-cellular).

A section of dry bone is similar to cartilage in that there are numerous small cavities in which originally were located the cells that formed the hard bony substance, which is entirely inter-cellular (Fig. 43).

Fig. 44. Cartilage from end of femur of frog. *c*, cartilage cells; *m*, matrix of inter-cellular substance formed by the cells; *c.s*, empty cell spaces. (*From Parker.*)

If we were to examine all the tissues besides bone and cartilage and all the organs of the frog's body, everywhere we should find cells and inter-cellular substance. We may

therefore make the general statement that the body of the frog is composed of cells and intercellular substance. But the latter is formed or secreted by the cells, and hence the cells are

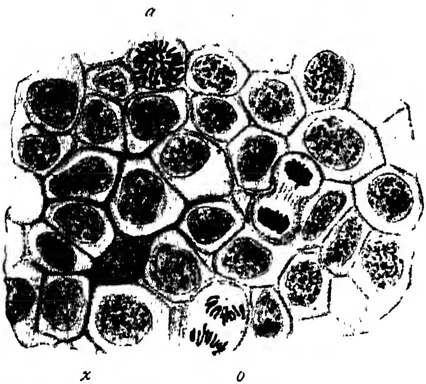

FIG. 46. Epidermis of salamander tadpole. Three cells undergoing division. (*From Wilson.*)

FIG. 45. Connective tissue. *c*, cells; *w*, white fibers; *e*, elastic.

the primary units composing the body. These statements are also true of all higher animals and of the human body.

94. Life-Activities in Cells: Protoplasm. — Since the bodies of all complex animals are composed primarily of cells, we are led to infer that the life-activities (§ 29) are located in the individual cells. For example, the shortening of a muscle when it contracts and moves is the

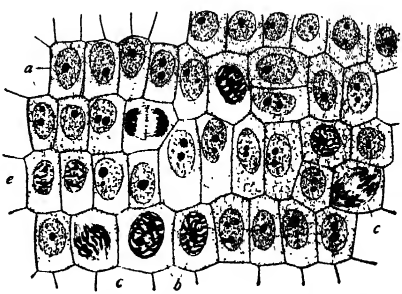

FIG. 47. Epidermis from onion bulb. Seven cells are in various stages of division. (*From Wilson.*)

result of the combined shortening of the thousands of cells of which the muscle is composed. It appears, then, that the living active substance is located in the cells of the body. The technical word for living matter is *protoplasm*. It is not known how much of the cell-substance is living; but it is certain that the protoplasm is the basic or essential substance in both nucleus and cell-body. The "life" of an animal, then, is not limited to any one organ, such as the heart, the brain, or the lungs; rather it is located in every living cell of the body.

In order to understand better that *protoplasm* is living and active, the microscope may be used to examine leaflets of certain aquatic plants in which the cells are so transparent that we can see the protoplasm moving (flowing) around inside the cell.

(*D*) Observe movement (streaming) of protoplasm in leaflets of Elodea, Nitella, or Chara — all of which are widely distributed aquatic plants. Mount leaflets in fresh water, and select transparent places for study with low power of microscope. In Elodea the bodies which contain the green-colored matter (chlorophyll) move with the protoplasm. Sometimes the movements are checked temporarily by the jarring involved in mounting, and it is necessary to let the slide stand for a half-hour or more before the protoplasm shows its most rapid motion.

III. THE WORK OF THE ORGANS OF THE FROG: INTRODUCTION TO ANIMAL PHYSIOLOGY *

95. Need of Food. — We shall now consider the work of the organs of the frog's body, and first we may inquire, Why does it need food? Some one may answer, "To keep its body alive," but that is not a scientific answer. In study-

* The statements made in this lesson may be directly applied to any higher animal.

ing science we want to know why and how food is used by animals so as to "keep going" the life-processes.

Waste. — A living animal is active in a number of ways, such as moving and breathing. These activities result in a loss of weight in the body-substance. In other words, the living body of the frog behaves like a machine in that all activity leads to wearing out. A new steam-engine begins to wear out as soon as it is put into motion, and at every working part, particle by particle, it is worn away. Likewise, the frog is a machine in which wearing out or *wasting* is continually occurring in every organ of the body; for though not always visible, every living cell of its body is continually working.

Repair and Growth. — Now, it is evident that this lost substance must be replaced by new substance, or the body will soon wear out and die. In other words, the *waste* which is always occurring in the living animal must be made good by the processes of *repair.* The materials for this repair are supplied by the animal's food. And in addition to materials for repair, food also supplies the materials required for growth, which means increase in number of cells.

What would be the effect on the weight of the body if the wasting processes were more rapid than those of repair? What are the conditions with respect to the rate of waste and repair in a young frog that is growing rapidly?

A scientific answer, then, to our question, "Why does the frog need food?" is that food (1) furnishes the new substances necessary for assimilation to replace the body-substances which have been wasted owing to activity; and (2) in addition to repairing, food may furnish the materials for growth. Especially do young animals need food for growth.

Energy. — The question "Why does the frog need food?" may be considered from another point of view. The

activities — breathing, eating, moving, etc. — indicate that the animal is continually doing work or using energy. Energy is the capacity for doing work. For example, the energy of the coal may move the steam-engine, the engine may run a dynamo and produce electrical energy, and the electricity may run a trolley-car.

Now, it has been discovered that energy cannot be created by any machine, plant, or animal; but energy may be transformed. Thus the energy of the coal is transformed into heat energy and the mechanical energy of the engine, the mechanical energy is transformed into electrical energy, and this into heat energy (electric heater), light energy (electric lamp), or mechanical energy (electric motor). A steam-engine does work and expends energy; but it derives its power of doing work (that is, its energy) from the coal burned in the furnace. Likewise the frog, being unable to create energy within itself, requires food as a source of the energy which is to be used in the life-activities. The food of the frog corresponds to the coal of the engine, in that each supplies the energy for its respective machine.

The value of the food of the frog or of the coal depends upon the amount of stored or potential energy which each contains. Thus a ton of one kind of coal may run a certain large engine eight hours, while another quality from another mine may make the engine work just as hard for ten hours. Likewise, the amount of energy in foods is highly variable. Chemists have methods of burning samples of foods and fuels and determining how much energy they are capable of furnishing; that is, how much stored or potential energy they contain. Such tests of energy value are especially interesting and important in connection with human food, and will be studied later.

In addition to supplying energy for the life-activities, we

should note that the food of the frog also supplies the materials for repair and growth of the frog's body, while the coal only furnishes energy and is powerless to repair the continual wear of the engine. Here is the great difference between a living machine, such as the frog's body, and the lifeless engine. Only the living machine, the animal's body, has the power of using food in order to repair the parts wasted by activity. When the animal's body grows old, it loses the power of using food to make repairs, and some of its essential parts wear out and stop the activity of the living machine.

Summary: Uses of Food. — We can now give a complete answer to the question, "Why does the frog need food?" by saying (1) food supplies energy, (2) food supplies the materials for repairing the waste of the living animal body, and (3) food supplies the materials for increase in size (growth), especially in the case of young, growing individuals. These three statements are true of all living things.

96. Changes in Food. — Having learned that food supplies materials for repair, growth, and energy of the frog's body, we now turn to trace it as it is taken into the body and undergoes the changes which take place internally when it supplies energy, builds up the body, and repairs the wasted body-substances.

In an earlier lesson we found that an animal body contains water, carbon, gaseous substances, and mineral substances. In order that food may serve for making new body-substance for growth or repair it must contain all these; in fact, all the chemical elements found in the body.

Dissolved Food. — The food which is taken into the mouth of the frog and thence passes through the esophagus into the stomach is largely solid, such as worms and insects. These must be reduced to a liquid condition before they can be *absorbed* through the lining of stomach and intestine into

the blood. Solid food retained in the stomach cannot fulfill its purpose of supplying the energy and materials for repair, for the reason that energy is being expended and repair is necessary, not only in the cells composing the stomach, but also in all living cells of all the organs of the body, even in the remotest parts, such as the fingers and toes. It is evident that solid food cannot be distributed so widely; but a *solution* (like sugar dissolved in water) can be absorbed by the lining of the stomach into tubes (blood-tubes) through which it can flow to distant organs and then "soak" into the cells. Hence we see the necessity of rendering solid food soluble in the water which is taken with food.

(*D*) A drop of milk, when examined with the microscope, is found to contain numerous fat droplets. Shake in a small bottle a few drops of oil, some dissolved soap and some water; and examine microscopically a drop of the milky mixture. This and milk are examples of *emulsions*. A drop of water containing some starch shows the small particles mixed with the water. Examining with the microscope a drop of water in which sugar or salt has been dissolved, no particles of these substances are evident.

Milk and the mixture of water and starch are examples of *fluids* or *liquids*, but they are not solutions. The particles of starch or fat are not dissolved (*i.e.*, not soluble) in the water. On the other hand, the water-and-sugar mixture is a liquid or fluid, and it is also a solution. It is clear that all liquids are not solutions. This distinction should be kept in mind for use in connection with the changes which foods undergo in the alimentary organs, for in them foods are chiefly prepared for absorption by being made into a solution in water. Even liquid foods like milk and soup must be dissolved so that no solid particles can be seen when they are examined with a microscope.

97. Digestion. — Some solid foods, such as sugar and salt, readily dissolve (are soluble) in water; but most of the

frog's food consists of meat and other things which have to be acted upon by certain substances before they will dissolve in the water which is taken into the food-tube. To this process of changing foods and causing them to dissolve the term *digestion* is given. Definition: *Digestion is the preparation of foods for absorption by the cells. It is partly a changing of foods so that they dissolve in water.*

In order to understand how a chemical change may make an insoluble substance capable of dissolving (soluble) in water, try the following experiment: —

(*D*) Place a very small piece of marble or limestone (or a piece of zinc) in water. Does it dissolve? Pour some dilute hydrochloric acid into the water, and repeat from time to time until the limestone (or piece of zinc) becomes dissolved in the water.

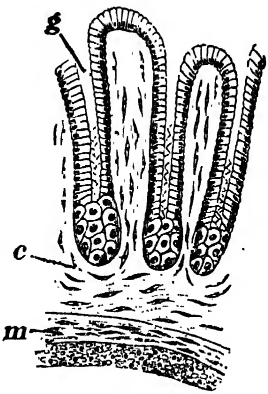

FIG. 48. Lining membrane of frog's stomach. *g*, gastric gland composed of epithelium; *c*, connective tissue; *m*, muscle coat of stomach. (*From Ecker.*)

From such experiments we learn that some substances which are not soluble in water will become soluble after a chemical change has been produced by an additional substance. This is just what happens in the alimentary canal of the frog. Small pocket-like tubes on the inside wall or lining of the stomach and intestine (called respectively gastric, Fig. 48, and intestinal glands), as well as the liver and pancreas, form or *secrete* peculiar fluids (called *secretions*), which are poured into the stomach and intestine. These, coming into contact with foods, change them so that they are dissolved in water taken with the food. When we say that the secretions of the

gastric and intestinal glands and of the liver and pancreas *digest* the various kinds of foods which the frog eats, we simply mean that the foods are dissolved and prepared so that they can be absorbed through the lining of the stomach and intestine into the blood-tubes. The nature of these digestive secretions and of their action on the various kinds of foods will be taken up more carefully in close connection with similar processes which occur in the human body. For our present purpose it is sufficient to point out that *digestion is preparing foods for absorption* through the cells which line stomach and intestine.

98. Distribution of Digested Foods. — We have noted reasons why digested foods must be distributed to all parts of the body (see § 96). We shall now consider the means by which this is accomplished.

Absorption. — If the frog were a small animal with all its tissues near the digestive cavity of the alimentary canal, the dissolved food could be absorbed through the walls of the stomach and intestine into the surrounding organs. This is the case in some very small animals of simple structure, such as Hydra. We can illustrate the absorption of digested (liquid) food in such a simple animal by the following experiment: —

(*D*) Take four sheets of blotting-paper (or filter-paper) about 4 by 10 inches in size, place them together, then roll them into a cone, and fasten with a pin. Dissolve common salt in water to make a strong solution, and pour into the cavity of the paper cone. Notice that the salt solution is absorbed first by the inner layer of paper, and then in succession by the outer layers, each layer absorbing from the next one nearer the center. Now unroll the sheets, mark the inner one No. 1 and the outer No. 4, and dry them. When dry, notice the crystals of salt on sheet No. 4, proving that the salt in solution has been absorbed from sheet No. 1 to 2, from 2 to 3, and from 3 to 4.

Some simple animals have a cylindrical body made up of several layers of cells which are in close contact similar to that of the layers of paper in the above experiment. (See Fig. 54, of Hydra.) In such simple animals the cavity in the center of the body is the digestive cavity in which food is prepared for absorption. The cells which line this cavity are in contact with dissolved food and can absorb directly, just as did sheet No. 1 in the above experiment; and the cells which form the outer layers must absorb from the inner ones, just as in the above experiment the outer layers of paper absorbed from those nearer the center.

99. Need of Blood for Distributing Food. — Absorption directly from the digestive cavity of the stomach or intestine would be possible only in a very simple animal. If in the above experiment we had used twenty or thirty sheets of paper, we should have found that very little salt solution would soak through to the outermost layer; and likewise in any animal with many layers of cells the outermost cells would get insufficient food if they had to depend upon absorption by layers, as in the case of the experiment with paper. Obviously, absorption directly from the stomach and intestine would not be possible in an animal like the frog, in which, as we have already learned by dissection, many organs are at some distance from the digestive cavities of the stomach and intestine. Clearly, then, there must be some method of transporting digested food from the digestive organs (stomach and intestine) to all parts of the body. *This is one work of the blood*, which, as we have already found, flows in a set of tubes, leading to all parts of the body. The details of the way in which blood carries dissolved food from the stomach and intestine to all parts of the body will be studied in a later lesson in connection with the same process in the human body. The important point for our

present study is that the frog needs blood and a mechanism (pumping heart) for moving it, in order to carry absorbed food from the stomach and intestine to all parts of the body; that is, to every living cell where it can be used as a supply of energy and as material for repair and growth. We shall later find two other important reasons why the frog needs blood.

100. Changes in Living Cells: Oxidation. — We turn now to the changes which occur in the living cells everywhere in the body of the frog. As has already been stated (§ 95), the continuous activity of the living animal causes a wearing out of the body-substance; that is to say, of the particles of cell-substance in the tissues composing the body. The wearing out changes are largely due to the chemical union of oxygen with the cell-substances, producing a kind of slow combustion or oxidation. We commonly think of combustion as the rapid burning of substances in the open air; but essentially the same kind of change may take place slowly. For example, a piece of iron wire can be quickly burned (oxidized) in a jar of pure oxygen. But in the oxygen of the air, diluted as it is with nitrogen, oxidation of iron is the very slow process of "rusting." Another example: A piece of magnesium wire may be burned quickly at a high temperature (§ 9); but if we place a piece of magnesium wire in water kept at the ordinary temperature, it will slowly oxidize (form a white powder on the surface). Now, the slow oxidation of the magnesium wire in water, or the familiar rusting of iron, illustrates the *slow chemical changes* which are *continually taking place in every living cell* of animals and plants. We emphasize the word "continually," for oxidation of the cell-substances is invariably associated with the activities which we call "living"; and as long as there is life in a cell, oxidation is going on and particle by particle the cell-sub-

stance and the food brought by the blood are being burned; that is, they are being combined with oxygen to form new substances.

Heat. — This slow burning (oxidation) results in heat, and this is how the human body is kept warm. In frogs and other lower animals the heat thus generated is lost rapidly, because the surface of the body is not covered with hair or other structures to prevent loss of heat, and so the frog is never perceptibly warmer than the water which touches its skin. We call it "cold-blooded," because it is usually colder than the human body.

101. Oxygen Required. — We have just learned that oxidation is a process necessary to the life of the cells in the frog's body. Oxidation requires oxygen; and therefore there must be in the cells of the frog a continual supply of that gas. In some very small aquatic animals oxygen is absorbed from the surrounding water by all the cells, and there is no need of any special organs for supplying oxygen. But in an animal as large as a frog, the cells of the internal organs are so far from the external air and water that some method of distributing oxygen is required, just as it is necessary that digested food be transported to cells which are far away from the digestive organs. The distribution of oxygen is accomplished by the blood, which absorbs oxygen from the air or water external to the body and then carries it to the internal cells. When the frog is under water, oxygen (a small quantity of O is always mixed with or dissolved in water exposed to the air) is absorbed by the blood flowing through the blood-capillaries in the skin; but when the animal is on land, oxygen is absorbed directly from the air, partly by the blood flowing in the capillaries in the skin and also by the blood flowing in the capillaries of the lungs. In our own bodies the blood absorbs most of the necessary

oxygen in the lungs. In fishes the blood flowing through the capillaries in the delicate membranes of the gills absorbs oxygen from the water just as the frog's skin absorbs some oxygen when the animal is under water.*

(*D*) Examine specimens of frogs' lungs with injected blood-vessels, frogs' skin with injected blood-vessels, gills of a fish injected to show blood-vessels. (These may be obtained by injecting with a hypodermic syringe or sharp-pointed pipette some colored mixture such as starch and carmine in water, into the large arteries of a frog which has been killed with anæsthetics.)

102. Excretions. — It has been stated that the cell-substance (including foods absorbed by cells) is continually being oxidized in every living cell of the frog's body. This chemical change produces a number of substances which are of no further use in the cells of the body; in fact, they would be poisonous if allowed to accumulate. These waste substances are called *excretions*.

We have already noted (§§ 11–15) that animal substance may be analyzed into water, gas, carbon, and mineral matters; and also that the gas and carbon may be burned. When food and cell-substance is oxidized in the living body, the chief excretions produced are of four kinds: *water*, *carbon dioxide* (a gas formed by burning the carbon of cell-substance), *mineral substances*, and peculiar substances containing nitrogen and called *nitrogenous excretions*. Three of these — water, carbon dioxide, and mineral matter — are easily shown to be present when animal matter is heated and burned in a pipe or tube (§ 13). Also it could be proved by a careful test that one of the gases given off when the meat is heated is ammonia; and this gas contains nitrogen, which is a constituent of the nitrogenous excretions formed when cell-substance oxidizes in

* To Teachers: Injected specimens suggested in § 48 of the "Applied Biology" are a useful part of the permanent equipment of the laboratory.

a living cell. It is true, then, that all the substances found when we analyze animal matter by heating and burning are also present in the excretions formed by oxidation which takes place at the temperature of the frog's body. The chief difference is that oxidation in the test-tube is rapid and at high temperature, while in the frog's body it is slow and at low temperature.

103. Removal of Excretions. — The excretions formed in all the living cells of the frog's body are poisonous if allowed to accumulate. Hence they must be eliminated from the body. Kidneys, skin, and lungs are the organs of excretion or excretory organs. Dissection of the frog showed that many cells are at such a distance from these organs of excretion that the poisonous substances cannot be absorbed directly by these organs, thus making it necessary that the blood should absorb excretions from the cells, and, flowing to the excretory organs, give up these excretions to be eliminated from the body of the animal. In the frog, the carbon dioxide is carried by the blood from the cells, where it is formed, to the skin and lungs, where it is given off to the air or to water. The nitrogenous excretions are first absorbed from the cells by the blood and then carried to the kidneys, where, along with water, these excretions are removed from the blood, passed into the ducts (ureters), and thence to the exterior. In some simple aquatic animals, the excretions are absorbed directly from the cells by the water in which the animal lives; and just as in the case of supplying food and oxygen to these animals (§§ 99, 101), there is no need of blood as a carrier of excretions.

104. Respiration. — This is a term which has long been used in physiology as almost a synonym for the popular word "breathing." It includes two of the processes which have been described; namely, taking in oxygen and giving out or

excreting carbon dioxide. In most animals the two processes go on at the same time and in the same organs. Air taken into the lungs supplies oxygen to the blood and at the same time absorbs carbon dioxide from blood circulating in the lungs; and hence the lungs are often called *respiratory organs.* Keep in mind for use in future lessons that respiration includes (1) supplying oxygen to cells, and (2) excreting carbon dioxide from cells.

105. Summary of Functions of the Blood. — We have found that blood and a mechanism for its circulation are necessary in the frog for communication between the living cells and certain organs which communicate with the external world. As we have seen, all cells must have a supply of food and oxygen and must get rid of the substances (excretions) resulting from the oxidation of cell-substances. Some small animals have all their cells near the places where food and oxygen must be absorbed and excretions eliminated; and for this reason such small animals need no blood-system. But in the frog, and in all except the simplest animals, there are cells at some distance from the organs which supply oxygen and food, and also far from those which eliminate excretions; and in all such animals the blood acts as a transporting medium which (1) carries food and oxygen to the cells from the organs (lungs and digestive organs) which obtain these substances directly from the exterior, and (2) carries excretions from the cells to the organs (lungs, skin, or kidneys) which pass them out of the body. In animals higher than frogs and reptiles the blood is also important in distributing heat and maintaining uniform temperature.

106. Nutrition. Fundamental Processes. — We have now briefly traced food from its entrance into the frog's body through the changes of digestion, absorption, and distribution to the living cells. These cells are active living ma-

chines requiring food (1) for repairing their waste and for growth, and (2) for oxidizing to give the energy which is expended in the activities of the body. Sooner or later most of the materials entering the cells as food become combined with oxygen, and the resulting substances are excretions of no further use to the living cells.

All the changes which food and oxygen undergo, beginning with their reception into the body and ending with their elimination in the form of excretions, involve the processes of digestion, absorption, circulation, respiration, changes within cells (*metabolism*), and excretion. It is important to remember that all these processes are fundamental, for one is just as necessary as another. All the processes — taking of food, digesting of food, its absorption by the blood, its transportation to the cells, its absorption by the cells, its use by the cells, the supplying of oxygen, and the removal of excretions — all these processes are linked together, as it were, in a chain, and each process must play its part in the life of the body.

107. Need of Organs Working Together: Coördination. — All the organs concerned in the processes named in the paragraph above must work together, for if any organ fails in the proper performance of its work, the result is that the working of all the organs of the body is affected. For example, if the heart beats slower, the blood flows slower, and consequently the supply of food and oxygen to the cells and the removal of excretions will be lessened. We know that if the heart stops beating, or the lungs cease acting, animals die at once; and the reason is that the cells of the body fail to get their necessary food and oxygen and the poisonous excretions are allowed to accumulate. We see then how necessary it is that all the organs concerned in the nutrition of the body should work together or coöperate. To accom-

plish this, there are organs which cause the *coördination* (working together) of all the organs of the body. These are the *nervous organs* of the body — the brain, spinal cord, and nerves.

108. Nervous Organs for Coördination. — If we touch a living frog anywhere on its skin, various muscles of the body will contract, causing the animal to jump. A similar result comes from suddenly thrusting a stick before the frog's eyes, or from making a loud noise. The same thing happens when the frog sees food, such as a worm; the muscles contract so that the frog jumps and seizes the worm. These are examples of coördination between the external organs (skin, ears, and eyes) and the muscles which move the body. Likewise, whenever any change takes place in any internal organs, coördinated changes in other organs, as in the beating of the heart mentioned above, are caused by the nervous organs. The activities of the nervous organs are due to the combined working of the nerve-cells (Fig. 49) and their fibers which connect them with various organs of the body. A large part of the nervous organs consists of connective tissues surrounding the nerve-cells and their fibers.

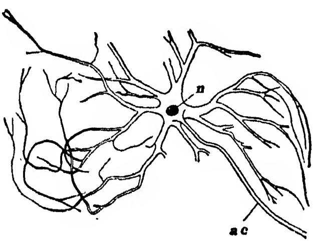

FIG. 49. A nerve-cell and its fibers. *n*, nucleus; *ac*, main fiber (axis cylinder). The other fibers are shorter and with many branches near the cell.

109. Reproduction of Frog. — The processes of digestion, respiration, circulation, excretion, and nervous activity are essential for the life of individual vertebrate animals; but reproduction is essential only for the procreation of new individuals to take the place of those which die from accident, disease, or old age. In Chapter XII the reproduction of various organisms is briefly described.

CHAPTER VII

SOME ANIMAL STUDIES PRELIMINARY TO HUMAN BIOLOGY: SIMPLE ANIMALS

The frog, the insects, and the plants that have been described in the preceding chapters have bodies composed of many cells, and hence they are called *multicellular* animals and plants. There are numerous species of organisms whose bodies consist of a single cell (*unicellular*). This lesson presents some unicellular animals which are not only interesting in themselves, but which help us to understand some of the human life-processes that will be considered in the next chapter.

I. THE STRUCTURE AND LIFE OF THE SIMPLEST ANIMALS

110. One-Celled Animals. — The simplest animals consist of one cell; that is, they consist of a small mass of protoplasm with a nucleus. Within this one cell must be carried on all the processes connected with the fundamental life-activities (feeding, breathing, excreting, reproducing), for each of which processes an animal like a frog has special organs with thousands of cells. In order to understand how an animal with one cell can carry on the same life-activities as does an animal with thousands of cells, it is necessary to study some examples of the simplest animals.

111. Paramecium. — (*D* or *L*) If some chopped hay be placed in water in a fruit-jar or other convenient vessel, and then to this be

added some decaying sticks, leaves, and other objects taken from a pond where aquatic plants are growing, there will probably develop within a few weeks large numbers of transparent animals appearing to the naked eye as minute whitish specks. With a rubber-bulbed pipette take a drop of water from the surface and near the edge of the vessel, and place on an object-slide. Then place a few shreds of cotton on the slide, and put on the cover-glass.

Place the slide on a piece of black cloth or paper, and notice the moving white specks. Use a hand-lens. Now examine with a microscope, using first the low-power objective. Look for rapidly moving objects having the form shown in Fig. 50. These are

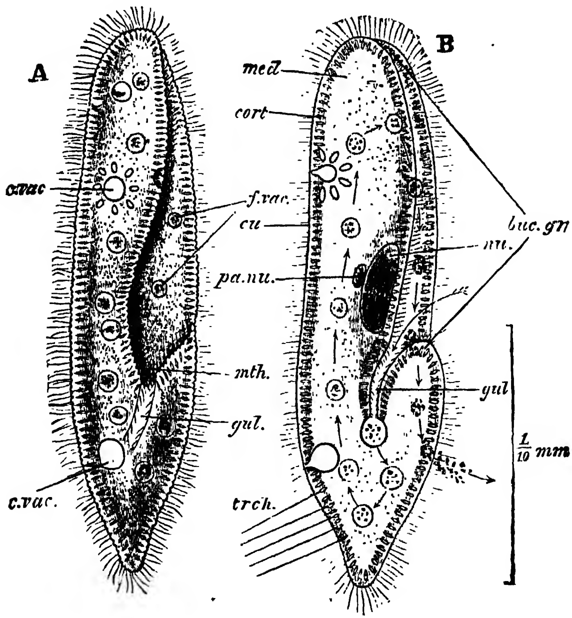

Fig. 50. Paramecium. *A*, viewed from below; *B*, interior of transparent body; *buc.gr*, groove for collecting food; *c.vac*, contractile vacuole; *cu*, cuticle; *f.vac*, food masses; *gul*, gullet; *mth*, mouth; *nu*, nucleus. (*From Parker.*)

specimens of paramecium, sometimes called the "slipper-animalcule." In size, they are about $\frac{1}{100}$ inch long. Several other species of similar animals are often abundant in the same water.

Study the following points: form of body, movements, response to stimuli (*e.g.*, when the animals bump against obstructions). One end is anterior (*i.e.*, goes forward in locomotion).

Mount and examine another slide with some paramecia which have been swimming for a half-hour in water containing powdered carmine, or lamp-black. Notice the action of the lashing *cilia* upon the particles of carmine surrounding the animal, and especially the collection of particles in the groove on one side of the body and then their entrance into the body through a tube or gullet. This taking of carmine illustrates how a paramecium gets food, chiefly bacteria and other small plants or animals. Notice that there is no stomach or other cavity into which food is taken, but simply particles of food surrounded by a film of water are forced into the protoplasm, which is soft and semi-liquid. These food masses (called food-vacuoles) move around inside the animal and digestive juices slowly dissolve the digestible food. The indigestible remains (such as hard parts of some small animals and plants often eaten, or the carmine particles in above experiment) are ejected at a soft spot in the cell-membrane.

Using the high-power objective, examine the cilia carefully. Look for the two clear spots shown in Fig. 50, *A*; they are spaces in the protoplasm filled with water, and when the surrounding protoplasm contracts the contents are ejected through a little canal leading out of the body. They are excretory organs, known as contractile vacuoles, and the water they eliminate contains some nitrogenous excretions. Sometimes they pulsate as regularly as the heart beats in higher animals.

Stained preparations should be examined for the nucleus. A small nucleus lies near the main nucleus.

Reproduction by Division. — Some of the paramecia seen swimming may be constricted near the middle of their bodies, as if an invisible thread were tied around them. The constriction grows deeper, and finally the animal is completely divided into two new and young individuals which swim independently.

112. Physiology of Paramecium. — A brief study of the life-processes of this simple animal will help us when we study the life of the human body. In some remarkable respects the simplest animals resemble other animals and humans.

Foods. — Like every other animal, a paramecium requires foods that have been made, directly or indirectly, by plants. These foods are taken in through its mouth and gullet, are digested by enzymes which are believed to be similar to those which cause digestion in higher animals, and the digested foods are absorbed by the protoplasm. Finally, the indigestible substances are ejected from the body.

Oxygen. — Like every other animal, it requires oxygen. It must breathe; but it has no lungs, as have higher animals. However, its delicate cell-wall allows the absorption of an abundance of oxygen from the surrounding water. Paramecia soon die in water from which the oxygen has been removed.

Oxidation and Excretion. — Like every other animal, a paramecium's food is constantly being oxidized to furnish energy to run the living machine, and this union of oxygen and foods forms excretions. As in a frog, these are chiefly water, carbon dioxide, and nitrogenous excretions. The carbon dioxide is absorbed by the surrounding water. The water and the nitrogenous excretions are pumped out by the regular pulsations of the contractile vacuoles. Thus, without lungs, kidneys, or skin, a paramecium gets rid of the same excretions which in the frog and other higher animals must be eliminated by these organs.

Assimilation. — As in every other animal, some food must be used continually for making new protoplasm by assimilation. Protoplasm is continually wearing out and some food must be used for repair. Also, the animals are frequently

dividing, and every new individual is half the usual size and must make enough new protoplasm to double its size before it can reproduce. Hence, much food must be used to make new protoplasm for growth.

No Circulation. — Especially is it noteworthy that, unlike the frog and other higher animals, a paramecium carries on its life-activities without organs for circulation (heart and blood-vessels). Turn back and review the reasons why a frog needs these organs (§ 105), and it will be evident that none of the reasons given applies to a paramecium, for that animal is so small that digested food, oxygen, and excretions do not require transportation to and from distant parts of the body. It is only a short distance from the surface of the body to the innermost particles, and so oxygen and carbon dioxide can diffuse as easily as they go through the wall of a blood-capillary in a frog. Also, the movement of the inner layer of protoplasm in a paramecium helps distribute food while it is being digested.

Irritability. — A paramecium has no nerves or other structures which appear to be substitutes for the nervous system in a frog; nevertheless the animal responds to stimuli caused by chemicals, touch, light, and electricity. It has no nervous organs, but it has *irritability* (response to stimuli) in a simple form.

Motion. — A paramecium has movement, and yet there are no visible muscles. Instead, the protoplasm of its entire body seems to have the power of movement or *contractility.* This is especially developed in the protoplasm of the cilia.

Reproduction. — And finally, a paramecium has the power of reproducing, without which its species would soon cease to exist. Since it consists of a single cell, its only possible way of producing new individuals is by cell-division, a simple process of *reproduction.*

Summarizing, we find in this simple animal all the life-processes which we find in higher animals; namely, movement, digestion, absorption, respiration, assimilation, oxidation, excretion, irritability (simple nervous activity), and reproduction. All these life-processes are within one cell in a paramecium, and require millions of cells in an elephant. But there is a difference in that the paramecium cannot perform any process as well as can a higher animal. In fact, to a large extent a paramecium is doing just what every individual cell in any higher animal is continually doing in carrying on its own life-processes.

113. Physiological Division of Labor. — The fact that the cells in higher animals are specialized to do certain work (*e.g.*, muscle cells to contract or cause movement, stomach cells to digest, kidney cells to excrete, nerve cells for coördination, etc.) is known as *physiological division of labor*. The advantage of such specialization is shown by an analogy from human society. Each pioneer in the country regions in America had to be his own baker, miller, carpenter, blacksmith, cobbler, etc.; because special workers in these lines were not near. But such a man never became expert in any of these lines; he was "a Jack of all trades, master of none." Nowadays in civilized communities a sociological division of labor has led men to become specialists and learn to do one thing excellently. But there must be a coördination or a working together. One man may specialize as a carpenter; but he must depend upon other men to be his cobbler, grocer, baker, farmer, and so on through a long list of people who must do things for the one who confines his work to one special line. In our great cities we do not often stop to think of this sociological division of labor which has grown up in our complex human society; but if all the grocers were to close their shops or, as has actually happened, the railroad

engineers should stop work and leave us without supplies, then we should realize the complex way in which we depend upon other workers in special lines of work.

All this from human society illustrates the division of labor in higher animals. For example, muscle cells have specialized for movement; but for them other cells must do the digesting, absorb the oxygen, discharge the excretions, etc. In short, the cells of every organ depend upon the cells of all the other organs; and all must work together harmoniously, because there is mutual interdependence. And just as a man specializing in one business becomes expert, so a cell specializing in movement, secreting, or in any other one necessary function, can do that work better than it is done in a paramecium, for that animal has so many things to do in its one cell that it does none of them as well as they are done by the specialized cells in higher forms of life.

114. Amœba. — In many ways the most interesting of one-celled animals is one belonging to the genus Amœba, which lives on the surface of submerged objects in ponds and other bodies of water.*

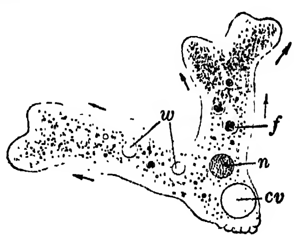

FIG. 51. Amœba. *n*, nucleus; *f*, food particles; *w*, water droplets; *cv*, contractile vacuole. (*After Wilson.*)

The body of an amœba consists of protoplasm, imbedded in which are many food particles that have been eaten and not yet digested. The outermost protoplasm is perfectly transparent and colorless, while the central portion is very granular and resembles ground or frosted glass. The microscope and

* TO TEACHERS: For directions concerning collecting and arranging amœbas for microscopic study, see § 270 in the "Applied Biology" and in the "Teachers' Manual of Biology." Demonstrate to the students the chief points mentioned in the text.

drawings give the impression that the animal is a thin sheet of protoplasm, spread out like a liquid poured on a flat plate; but when the animal is disturbed (as by jarring) it rolls up into a rounded mass.

Movement. — The most noticeable thing about an active amœba is that it is continually changing its shape. Close observation will show that this is due to the fact that the animal is composed of semi-fluid protoplasm which is constantly flowing. This movement of the protoplasm is not like the flowing of water down an incline, but is due to contractions originating within the amœba itself. It is possible for the animal to crawl up the stem of a water plant, and this could not be explained by the laws of gravitation.

When the animal is actively moving, long arm-like projections, called pseudopods (false feet), are formed, and then granules from the main body continue streaming in the same direction. In fact, the motion reminds one of the flowing of lifeless liquids, and we can imitate it by pouring some thick liquid (molasses, melted gelatin, or mucilage) on a plate, and then by tilting cause the liquid to flow in various directions. Notice that when a streamlet starts in one direction, the liquid all tends to flow in the same direction.

Sometimes a *nucleus* can be seen in a living amœba, but it is very prominent in a stained preparation.

In large specimens it is easy to see the one *contractile vacuole,* which acts essentially like those seen in a paramecium, and has the same function of excreting water containing nitrogenous waste.

Food. — The taking of food can sometimes be observed when an amœba is moving actively. If it comes in contact with a small animal or plant, two pseudopodia flow out and gradually surround and inclose the food particle in the protoplasm of the amœba. A small amount of water surrounds

the food particle, just as in a paramecium. Sometimes an amœba is seen so filled with food particles that the body substance is opaque. The protoplasm of amœbas secretes digestive *enzymes* which dissolve the proteins, etc., in the animals and plants which are captured. The digested foods are then absorbed by the surrounding particles of protoplasm, and when the amœba moves, the particles being digested are circulated so that dissolved food is widely distributed. Indigestible particles (hard parts of small animals and cell-walls of plants) are from time to time ejected; the protoplasm of the amœba appears to flow away from them as water on a board might for a time surround and inclose some grains of sand and then flow away and leave them behind.

Oxygen. — An amœba, like a paramecium, absorbs oxygen from the surrounding water.

Excretion is the same as in a paramecium; carbon dioxide is absorbed by the surrounding water, and water and nitrogenous excretions are pumped out by the contractile vacuole.

Reproduction. — Amœbas are rarely seen dividing (Fig. 52), but if kept in watch-crystals they multiply rapidly, making it evident that they must undergo *division* frequently. Under conditions unfavorable to the usual activity, amœbas will sometimes become rounded, and secrete around themselves a hard wall or *cyst*. They are said to be *encysted*. In this condition they are able to live for

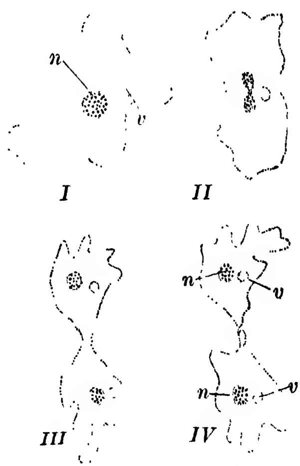

FIG. 52. Diagram showing division of an amœba. *n*, nucleus; *v*, contractile vacuole.

some time without food and in a dry state. Such a habit insures their existence in dry seasons when the ponds are dry. Also, in the dry condition they may be widely scattered by winds.

115. Allies of Amœba and Paramecium: Protozoa. — These animals are members of the lowest division of the animal kingdom, a group of animals which are characterized by the fact that their bodies consist of one cell. Any one-celled animal is a *protozoan* (meaning first animal), and the entire group of them is named *Protozoa*. There are numerous species, but most of those known are like the amœba and paramecium in being of interest because a study of them has helped much towards explaining the life of higher organisms, including man himself. A few protozoans are now known to be of very great practical interest. Certain species live as parasites in the blood of men and animals and cause disease. Examples of diseases so produced are malaria, and Texas cattle fever. Many protozoans are important as scavengers and as the food for larger animals. (See "Applied Biology," § 277.)

For the position of Protozoa in the animal kingdom, see the table of classification in § 87 of this book.

II. SIMPLE MANY-CELLED ANIMALS

The one-celled animals represent the simplest animal life, and the frog belongs to the most complex group (the vertebrates). In the frog there are many organs, each composed of thousands of cells. It will now be interesting and useful to study an animal which has numerous cells, arranged in a very simple body that is able to perform all the life-processes found in the frog.

116. Hydra. — Much more differentiated than the one-celled animals, but exceedingly simple as compared with a

backboned animal, are those of the group to which belong the jellyfishes and coral-animals. Most of these live in the sea, but among the few species which live in fresh water are the little animals known as hydras, and belonging to the genus Hydra. They commonly live in ponds and streams, clinging to aquatic plants, dead leaves, and sticks.

I. (*L*) Observe hydras in glass jars (aquaria) near windows. In what part of the aquarium with reference to light and shade are they most abundant? Note the long thread-like arms which are attached at the free end of the animal. Study a hydra which has been removed from an aquarium to some water in a watch-glass. Use a hand-lens. What is the shape of the body? Does the shape change? Disturb the animal by touching it with a needle. Describe what happens. How may this reaction be of use to the hydra? Notice that one end becomes attached to the glass; this is the *base*. Find out if the hydra has a firm hold on the glass dish, *e.g.*, try to wash it off with a gentle jet of water from a pipette. At the free end is a circle of *tentacles*. How many? These are used for catching the prey. On the summit of a conical elevation in the center of this circle of tentacles is a small opening, the *mouth*, which is usually very difficult to see. How do the tentacles behave when the hydra is disturbed? Can the tentacles move independently of each other? Is this animal bilaterally symmetrical?

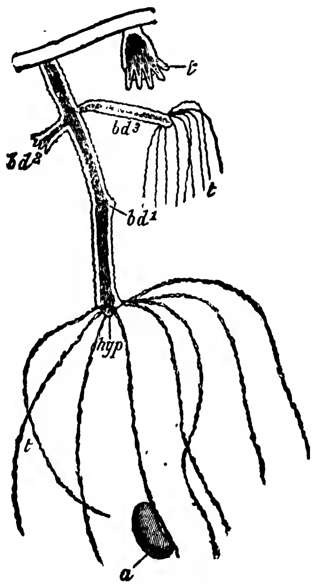

FIG. 53. Two specimens of hydra, one contracted and one expanded. The latter has three buds in stages of development ($bd^{1,2,3}$). *t*, tentacles; *a*, captured water-flea; *hyp*, position of mouth. (*From Parker.*)

Often young hydras may be seen

attached to the bodies of the larger ones, and these are formed by outgrowths or *buds* (Fig. 53).

Make an outline drawing of a living hydra, showing as many structures mentioned above as possible — (1) fully extended, (2) contracted.

II. (*L*) Transfer a hydra, with a little water, by means of a clean pipette, to an object-slide. Be careful to support the cover-glass (small bits of broken cover-glasses may be used as supports) so as not to crush the animal. Examine with low power of the compound microscope. Notice that there are two layers of the body-wall; the outer (*ectoderm*) is colorless, the inner (*endoderm*) is green or brown. The green is due to the presence of chlorophyll. In the outer clear layer, look for knob-like swellings, especially on the tentacles. These swellings contain the stinging or *nettle threads*, which are organs of defense, and also used for spearing and paralyzing water-fleas and other small water animals.

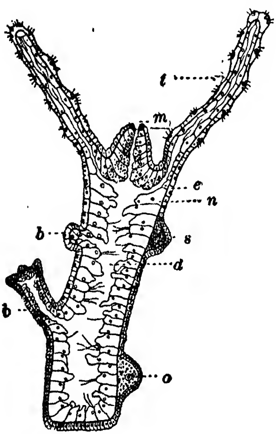

FIG. 54. Longitudinal section of a hydra. *t*, tentacle; *m*, mouth; *e*, ectoderm or outer layer of cells; *n*, endoderm or inner layer; *d*, digestive cavity; *b*, buds; *s*, spermary; *o*, ovary. (*From Parker.*)

III. (*D* or *L*) *Microscopic Sections.* — Examine with a compound microscope a permanent slide with longitudinal sections of hydra and observe: —

A hydra is really a hollow cylinder, the interior of which is the digestive cavity (Fig. 54).

The tentacles are hollow outgrowths of the digestive cavity.

The mouth is the only opening from this cavity to the outside.

The body-wall is composed of layers of cells on both sides of a deeply-stained line in the preparation. The outer layer is the *ectoderm:* this is the colorless layer seen in a living hydra. The deeply-stained line (middle layer) is not made up of cells, but consists of a gelatinous substance. The inner layer of large cells is the *endoderm.*

Look for these three layers in a section of a tentacle. In the ectoderm of the tentacle look for the stinging cells or nettle-cells

(Fig. 55). Each of these contains a sac filled with fluid and surrounding a coiled stinging thread. If a small animal happens to touch a hair-like projection (trigger) on the outer edge of one of these cells, the stinging thread is suddenly ejected and spears the victim. It appears that some paralyzing fluid is injected, for the animal caught seems benumbed. Finally, the tentacle bends over towards the mouth and the captured food is taken into the digestive cavity. The nettle-cells may also be used for defense against animals too large for the food of a hydra.

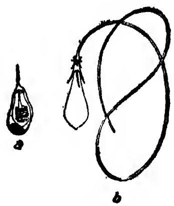

FIG. 55. *a*, stinging cell with thread inclosed; *b*, thread discharged. Those on the tentacles of a hydra are similar. (*From Hatschek.*)

If there is a bud present on the section, notice the relation of its digestive cavity to that of the parent.

Study a transverse section of a hydra and compare with the structure in the longitudinal section.

117. Physiology of Hydra. — The life-activities of a hydra are more specialized than those of one-celled animals, but they are exceedingly simple as compared with those of an animal like the frog.

Digestion. — Small animals caught by the tentacles and forced into the digestive cavity through the mouth are softened and disintegrated by the action of the digestive juice secreted by the cells of the endoderm which lines the cavity. The digestible particles set free by the disintegrative action of the digestive juice are taken in by endoderm cells, the free ends of which are amœba-like and able to take in food in the way that an amœba does. Particles thus taken into the cells are completely digested (dissolved). This is *intra-cellular digestion* (*i.e.*, within cells), and is the same as the only possible digestion in Protozoa and Porifera. But in the hydra there is a decided advance over the lower animals in that the cells able to digest intra-cellularly are

grouped so as to form the lining of a cavity (digestive cavity) into which they pour secretions that cause digestion outside of the cells. This digestion in a cavity, as in the stomach of all higher animals, is *extra-cellular digestion*, *i.e.*, occurs outside of cells. The digestive cells in a hydra, then, in part resemble the one-celled animals and the digestive cells of sponge-animals; and in part the lining cells of the stomach of higher animals.

Absorption of Digested Food. — The cells (endoderm) which line the digestive cavity of a hydra can either get food by taking in particles and digesting them inside of cells, or by absorbing foods digested in the cavity. The cells of the outer layer (ectoderm) must get all their food by absorption or osmosis from the endoderm cells. This osmosis of food from cell to cell is accomplished as easily as water soaks through several layers of paper.

Use of food in cells of the hydra is the same as in all other animal cells. Some food is used to make new protoplasm for repair and growth, and some serves as a source of energy.

Oxygen is absorbed by all cells in contact with water. This includes the majority of the cells, for even the digestive cavity contains water taken in with the food. But probably the larger part of the oxygen needed is absorbed from the water by ectoderm cells.

No Circulatory Organs. — Although a hydra is multicellular, it is able to live without circulating blood and lymph for the reason that its simple cylindrical body allows digested food and oxygen to reach all cells by osmosis, and all excretions are eliminated by the same process. Compare this with the distribution of digested food, oxygen, and excretions in a frog.

Excretion is accomplished by osmosis of waste matters from the cells to the surrounding water. Probably the ectoderm cells do the larger share of this work.

Movement is caused partly by contraction of cells and partly by that of muscle-processes which are extensions of some cells in both inner and outer layers.

Irritability is well developed in the hydra. It is in part a function of all the constituent cells; but some cells believed to be simple nerve-cells are near the nettle-cells, which must be extremely sensitive in order to discharge the nettle-threads when stimulated by other small animals.

Reproduction of hydras is sometimes by budding as shown in Fig. 54, and at other times from fertilized eggs. This process will be described in § 332.

118. Division of Labor in Hydra. — All cells must use food, but only the endoderm cells are able to digest food. Hence, ectoderm cells must depend upon the endoderm cells for their food. On the other hand, the ectoderm cells form the external protective covering of the animal, furnish the cells which form the reproductive organs, catch the food, receive impressions from the environment, and probably are the chief causes of the movements of the animal. The tentacles are specialized for collecting food, and their nettle-cells still more highly adapted to a special purpose. The presence of simple nerve-cells suggests the beginning of differentiation of nervous organs.

119. Classification of Hydra. — The simplest animals are the one-celled Protozoa (§§ 110–115), next highest in complexity are the sponge-animals (Porifera), and then next are the cœlenterates (Cœlenterata), examples of which are hydras, sea-anemones, jellyfishes (medusæ), ctenophores, and coral-animals. For descriptions and pictures of any of these, consult the indexes of any textbooks of zoölogy or the author's "Applied Biology." The flat-worms and round worms are the groups of animals just above the cœlenterates in complexity of structure. The reader should bear in mind

that " higher " as applied in comparing animals and plants means more complex in structure, and *vice versa,* " lower " means simpler in structure. We classify organisms entirely according to structure, grouping together those that are most similar.

See the position of the cœlenterates in the table of classification in § 87.

CHAPTER VIII

HUMAN STRUCTURE AND LIFE-ACTIVITIES

120. Human Biology. — Biology is the science of living things, and human biology may be defined as the study of man considered as a living thing and interpreted in the light of studies of other living things.

The justification for including study of man as part of biology is found in the fact that the human body in its structure and functions is remarkably like that of animals, the higher forms in particular. In the body of man are the same organs as in the animals known as beasts or mammals; and the organs of man and the beasts are closely alike even in microscopic details. This similarity also appears when comparing man with still lower animals. In short, when biologists consider the close similarity of structure and function in man and various types of animals, they see no escape from the conclusion that man's relation to the animal kingdom is as stated in the next paragraph.

121. Classification of Man. — (1) As suggested above, man belongs to the animal kingdom, because his body is built on the plan of structure found in many animals. (2) Man is a backboned or vertebrate animal, because he possesses a backbone or vertebral column. (3) Man belongs to the class of mammals or Mammalia, because he has the three characteristics of this group, — hair, diaphragm, and milk or mammary glands. (4) Man belongs to the order of the Primates, because his body is in numerous respects more

similar to apes than to other animals. (5) Man belongs to the human family, the genus *Homo*, and there is now only one species, *sapiens* (a word meaning "wise," and referring to the fact that man's intellectual development is characteristic and markedly distinguishes the human species from all other animals). In fact, it is in the highly developed functioning of the nervous system alone that man stands distinctly differentiated from the highest apes and other animals. This, however, is the proper field of the science of psychology (the study of mind or mental phenomena), which should be taken up in college or in private reading after graduation from high school. So far as biology is directly concerned, it has to take into consideration simply the demonstrated fact that man and other animals are remarkably similar in structure and functions. This similarity is fortunate, for it makes possible the application to human biology of many facts which were first learned by the study of various animals. (6) Finally, the existing human species has five varieties or races, — Caucasian, American Indian, Mongolian, Malay, Ethiopian, — each with certain peculiarities.

(*L*) Look up these races in any advanced textbook of geography, or in an unabridged dictionary, and report briefly concerning their characteristics and geographical distribution.

Study of the customs, character, history, and institutions of races of men is the science of ethnology. The science dealing with the laws of human society is sociology. General study of man, combining facts of ethnology, biology, psychology, and sociology, is anthropology. The following brief definitions in parentheses will help the memory: *psychology* (science of mind); *sociology* (science of society); *ethnology* (science of human races); *anthropology* (science of man). Each of these lines of study of human life is now so

highly developed that special books are necessary; but they all are founded on biology to such an extent that a knowledge of that science is important for the reader of any of the special sciences dealing with man.

122. General Plan of Human Body. — Like the frog, already studied, the human body consists of head, trunk, and limbs. The trunk is composed of the chest or *thorax*, and the belly or *abdomen*. The arms are the upper or anterior limbs; the legs are the lower or posterior limbs. The thigh of a leg corresponds in structure to the upper arm, the shank to the forearm, the ankle to the wrist, the toes to the fingers. Externally the body is bilaterally symmetrical.

123. Skeleton. — Like the frog and all the other backboned animals, the human body is supported by an internal framework or skeleton composed of bone and cartilage, the latter chiefly at the ends of bones. There are more than 200 bones in the human skeleton; 33 vertebræ or segments of the spinal column, about 25 bones in the skull of an adult, 24 ribs, 30 bones in each arm and leg, and the bones in the shoulder-girdle and pelvis. The number of bones varies with the age; for example, the skull bones are more numerous in young children, but they grow or fuse together as the individual becomes older. Each half of the pelvis is composed of three bones which have fused together. Nine bones (vertebræ) at the posterior end of the spinal column are fused together in connection with the pelvis, leaving 24 separate vertebræ.

(*L*) The best way to study the human skeleton is to compare a mounted skeleton with labeled drawings (Fig. 56). At the same time the pupil should locate the position of the larger bones in his own body. If a mounted skeleton is not owned by the school, the pupil should locate as nearly as possible the bones in his own body,

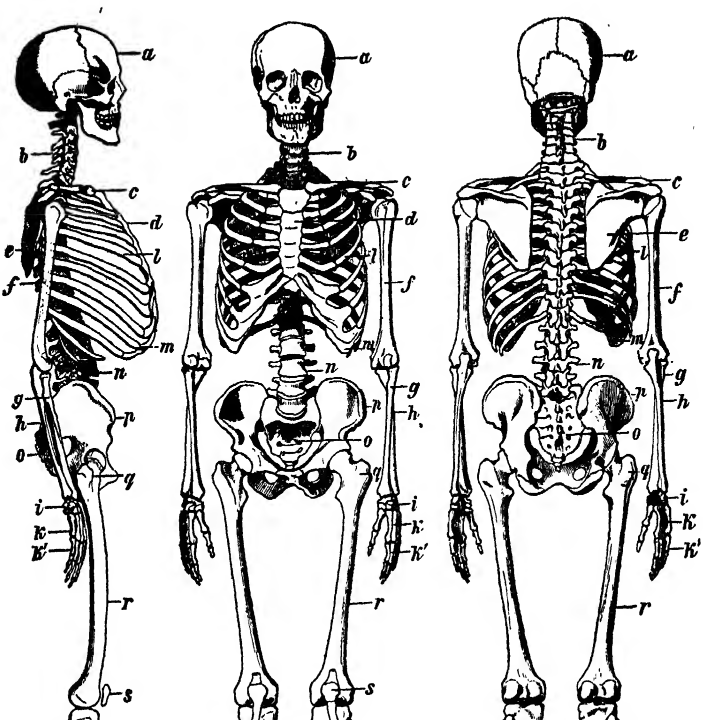

FIG. 56. *a*, skull; *b*, neck or cervical vertebræ; *c*, clavicle; *d*, sternum; *e*, scapula; *f*, humerus; *g*, radius; *h*, ulna; *i*, carpals (wrist); *k*, hand; *l*, ribs; *m*, sternal cartilage; *n*, vertebræ; *o*, coccyx; *p*, pelvis; *r*, femur; *s*, patella or knee-bone; *t*, tibia; *u*, fibula; *v*, heel; *w*, ankle; *z*, toes.

using labeled pictures as a guide. The names of the large bones are so frequently referred to that it is desirable to memorize them. Pupils who are studying drawing will find various parts of the skeleton good objects for sketching; but as a rule this work is not possible in the limited time available for the biology class-work.

The most important parts to notice while examining a skeleton are: (1) The backbone or vertebral column, to which all other parts of the skeleton are attached. It is the central supporting axis of the body. (2) The bones of the two pairs of limbs, comparing the anterior with the posterior pairs. (3) The ribs and the bones which connect the arms with the backbone. (4) The pelvis, which connects the legs with the backbone. (5) The larger bones of the skull.

124. Body-Wall and Body-Cavity. — As in the frog, the outer, fleshy wall which incloses the internal organs is the body-wall; the internal cavity is the *body-cavity*. In the frog there is one cavity in which lie the heart, lungs, liver, stomach, intestine, kidneys, and reproductive organs. In the human body the diaphragm forms a partition across the body-cavity, dividing it into the anterior (upper) cavity containing the heart and lungs and known as the thoracic cavity (chest-cavity), and the posterior (lower) abdominal cavity, which contains all the internal organs except the heart and lungs. The thoracic cavity is inclosed by the ribs, while the abdominal cavity is bounded by the muscular walls of the abdomen.

Structure of the Body-Wall. — (*D*) This is essentially the same in man and other mammals, and so we may study any of the animals found in meat-markets. A slice of bacon will serve our purpose. On the one edge of the slice is the skin or "rind." This, of course, was the skin of the pig. The streaks of lean meat are muscles of the body-wall. Fat has been deposited in the connective tissue between the muscles, and also between the muscles and the skin. The thickness of the body-wall depends upon the amount of fat; hence very lean bacon is relatively thin. Notice that the skin

is fastened firmly to the muscles and fat; this is due to fibers of connective tissue. In some parts of the body of mammals the skin is not fastened down so closely as in bacon; *e.g.*, note the loose skin on the back of your own hand, or on the backs of young puppies.

125. Relative Positions of Internal Organs in Man.— Study diagrams (Fig. 57), charts, and a manikin, if available; and note the following positions of the largest organs, which are in the same relative position as in the frog. (1) The body-cavity is ventral to the backbone. (2) The alimentary canal extends through the body-cavity from anterior to posterior. (3) The heart is ventral to the alimentary canal (esophagus part). (4) The liver lies ventral to the alimentary canal (stomach and intestine part). (5) The kidneys lie dorsal to the alimentary canal and in the posterior part of the body-cavity (abdominal part). (6) The brain and spinal cord lie in the cavities formed by the bony skull and the backbone.

126. Life-Activities of the Human Body. — The characteristics of living things already studied in connection with animals and plants apply to the human body, for it is a living mechanism which performs the functions necessary for life.

The life-activities are located in the cells; and these, as in the case of the frog, are in the tissues (epithelial, connective, muscular, bony or osseous, cartilaginous, and nervous).

(*D*) If preparations of human tissues are available, they should be exhibited and compared with Figs. 39–44. Epithelial cells should be scraped gently from the lining of the mouth and mounted under a cover-glass on an object-slide. Examine first unstained, and then stain by drawing (with absorbent paper) some iodine-eosin or other dye under the cover-glass. Note that these cells overlap; it is because there are many layers of flattened cells in the epithelium of the mouth. In fact the lining of the mouth has the same structure

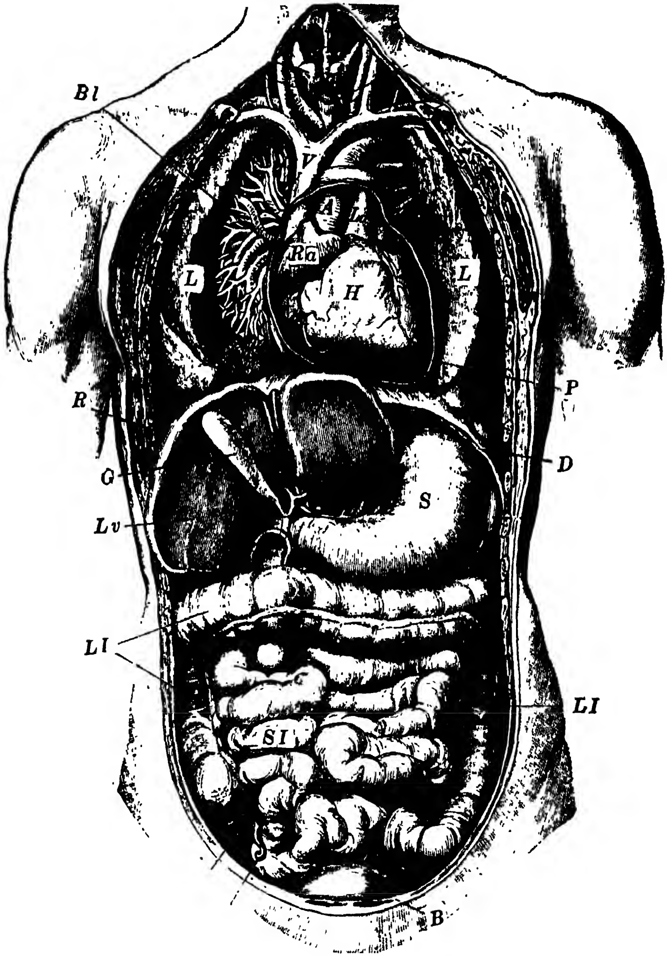

FIG. 57. *A*, aorta (main artery); *B*, bladder; *Bl*, bronchial tubes; *D*, diaphragm; *G*, gall-bladder; *H*, heart; *L*, lungs; *La*, pulmonary artery; *LI*, large intestine; *Lv*, liver; *P*, pericardium; *R*, ribs; *Ra*, right auricle; *S*, stomach; *SI*, small intestine; *V*, main veins. (*From Schilling.*)

as the skin on the lips. A piece of horny outer layer of skin may be scraped from a calloused spot on the palm of the hand, and after some soaking in a drop of caustic soda solution, the dried scale-like cells will swell.

Probably the two activities of the human body which most attract our attention are eating and breathing. Moreover, these are the basis of all the other processes occurring in the human body. For these reasons we shall specially consider the taking of foods and oxygen into the human body, and later we shall trace the changes of foods and oxygen in the body. This will lead us on to consider all the essential life-activities.

FOODS

127. What are Foods? — A convenient definition for our present purposes is that foods are solid or liquid substances which when taken into the alimentary canal are useful in the life-processes of our bodies. In most cases substances able to serve as our foods must be capable of being digested and absorbed as materials for energy, repair, and growth; but a certain amount of indigestible plant tissue is useful in the human alimentary canal.

Sources and Kinds of Human Foods. — (*L*) Write in your notebook a list of some common foods, arranging in three columns those of animal, plant, and mineral origin.

128. Nutrients. — We might consult cook-books and make a very long list of the names of prepared foods which are served on our tables; but these are made by combinations of such common ingredients as meats, vegetables, milk, butter, lard, sugar, flour, starch, chocolate, salt, etc. Chemists have shown that these common things which are used in every kitchen in combining our foods are composed

of certain chemical compounds known as sugar, starch, fat (oil), proteins, and minerals. These compounds, from which all the combinations of human foods are made, are known in physiology as *nutrients.*

In order to prove that various foods are made up of these few nutrients, we need to know some method of identifying each. Fortunately, chemists have discovered some simple tests which are easily applied, as directed below.

129. Chemical Tests for Nutrients. — Certain chemicals produce characteristic reactions on nutrients and hence may be used to detect their presence in mixtures of foods.

Starch Test. — (*D* or *L*) Repeat the iodine test with diluted starch paste (§ 64).

Sugar Test. — (*D* or *L*) Boil a few grapes, raisins, or prunes in water in a test-tube for two minutes, and this will extract some sugar. Into another test-tube put some Fehling's reagent,* the ingredients of which are usually kept in separate bottles and mixed when needed. Heat the Fehling's reagent, and then with a pipette slowly drop into it some of the sugar solution obtained from the dry fruits; or drop some of the reagent into the sugar solution. A red colored precipitate indicates the presence of one kind of sugar. One such experiment could not prove that when Fehling's reagent causes a red color it means that sugar is present, for we have not yet tried this solution on starch, fat, and other things. However, chemists have tried the Fehling's reagent on all the substances commonly found in animals and plants, and it has been demonstrated that only certain kinds of sugars produce the red color. We have not time to repeat such investigations, and so we must accept the chemists' statement that Fehling's reagent is a test for a sugar found in grapes and known as grape-sugar or dextrose. The sugar in corn-sirup is popularly called glucose. Its chemical formula is $C_6H_{12}O_6$.

Tests for Fat. — (*D* or *L*) Put a drop of olive oil on a sheet of white paper, and note that a grease-spot is produced. Dissolve some beef-

* Fehling's reagent, a test for certain kinds of sugar, may be purchased from dealers in chemicals or at ordinary drug-stores. It may be made according to the formula in the "Teachers' Manual of Biology," which accompanies this book.

suet in a small quantity of benzine or ether (keep such volatile liquids as these far away from a flame), put a drop of the solution on paper, and notice the spot left after evaporation of the benzine. Or lay a piece of suet on a paper and heat slowly. This "grease-spot" test is a simple way of finding whether abundant fats or oils are present in foods.

Tests for Protein. — (*D* or *L*) Mix a small quantity of white-of-egg in water in a test-tube, shake well, add some strong nitric acid, boil until the solution turns yellow, cool, and then add drops of ammonia until an orange color appears. Or instead of the acid, add to the egg-albumen in water some drops of Millon's reagent (mercury dissolved in nitric acid, obtainable from chemists), heat slowly, and red color will appear, especially after cooling.

Tests for Water and Minerals. — The loss of weight by drying foods is chiefly due to evaporation of water. The ashes left after burning foods represent the mineral contents. By complicated processes chemists can analyze the ashes and determine the kind and proportion of elements present.

130. Sugars and Starches: Carbohydrates. — All sugars and starches are grouped together under the name of *carbohydrates*. They contain but three elements: carbon, hydrogen, and oxygen. We have already learned that starch is formed in plant cells which have chlorophyll, and that starch is readily digested by enzymes into sugar, or sugar turned back again to starch for storage. The carbohydrates which are used as human foods are chiefly cane-sugar or sucrose and milk-sugar or lactose (both with the formula $C_{12}H_{22}O_{11}$); grape-sugar and fruit-sugar (both with the formula $C_6H_{12}O_6$); and starch and dextrin (whose formulas are some multiple of $C_6H_{10}O_5$).

As we have seen, grape-sugar is found in raisins and other fruits. Under the names of glucose and corn-sirup it is common in the markets, and is made by treating the starch of corn grains with strong sulphuric acid. Lactose or milk-sugar is sold in all drug-stores for use in preparing foods for

infants and invalids. Malt- or barley-sugar (maltose) is also sold, especially for flavoring candies, etc. The common "granulated" sugars in our markets are sucrose from the juices of sugar-cane and sugar-beet. The yellow and brown sugars are the crude ones obtained by evaporating the juice pressed from cane and beet; and by refining processes, these dark-colored sugars are made into the "soft white" and "granulated" sugars. Maple sugar, from the sap of maple trees, is chemically the same as cane-sugar, but flavored with peculiar substances found in the maple sap.

131. Fats. — This includes all kinds of fats and oils from animals and plants. Common examples are butter, lard, beef-suet or tallow, olive oil, cotton-seed oil, fat of meats, oil of nuts. Like the sugars and starches (carbohydrates), fats contain only three elements: carbon, hydrogen, and oxygen; but they have much carbon. The sugars, starches, and fats taken together are often called "non-nitrogenous foods," because they have no nitrogen.

132. Proteins. — Formerly spelled "proteids." Also called albumens. White-of-egg ("egg-albumen"), lean meat, and milk curds have abundant proteins. They contain carbon, hydrogen, nitrogen, oxygen, and sulphur. Also, some have phosphorus and iron. All proteins differ from carbohydrates and fats in having nitrogen and sulphur. As already stated, only plants can make proteins, and animals must get them directly or indirectly from plants.

Gelatin is the most common example of certain food substances which have the composition of proteins, but which cannot take their place as food. Dogs have been found to live well if fed pure protein from lean meat; but with gelatin alone they soon begin to lose weight and to show other evidences of starvation. Hence, gelatin must be used with other protein foods.

133. Inorganic or Mineral Foods, and Water. — The inorganic foods are the only ones not formed by animals or plants. As we have seen, water plays an important part in all living matter. In the human body it is especially important in dissolving foods during digestion, and also as the circulating medium in the blood- and lymph-systems.

Common salt (sodium chloride, NaCl) is only one of a number of mineral salts necessary in the human body. A compound containing iron gives the red color to blood; lime (calcium) is necessary in the bones; and less noticeable quantities of other elements (P, K, S, Mg) are needed in the human body. Most animal and vegetable foods which we commonly use contain these necessary elements, and so we do not have to give any special attention to obtaining them. Common salt is the only mineral food which is regularly added to our diet in addition to what is naturally in our organic foods; and it is probably true that we use this greatly in excess of what the body actually requires.

134. Foods are Combinations of the Nutrients. — From the foregoing experiments, it is evident that one or more of the nutrients is present in each of the common foods. Chemists have proved that the useful constituents of all our foods are carbohydrates, fats, proteins, mineral salts, and water. The experiments below show that some foods have a preponderance of certain nutrients; *e.g.*, white-of-egg is chiefly protein, potato is chiefly starch, corn-sirup is almost pure sugar, butter and beef-suet are largely fat. It is evident that if all the nutrients are needed in human diet, they can best be obtained by a mixture of foods; that is, a meal composed of lean meat, potato, bread, butter, and some form of sugar might be arranged to supply equal amounts of protein, fat, sugar, and starch. We shall see later that *equal* amounts of these nutrients are not needed; but that a

mixture of foods is necessary in order to give the proper amount of each of the nutrients of which our common articles of food are composed.

Testing Foods for the Nutrients. — (*D* or *L*) Apply the tests for starch, proteins, and grape-sugar to oatmeal, flour, white-of-egg, egg-yolk, potato, onion, rice, beans, peas, lean meat, apple, honey, corn-sirup, pears, corn-meal, and other common articles of food. Place each food to be tested in some water in a test-tube, boil for a few minutes, and then pour in the testing reagent to be used. Make a table in your note-book and record the results of the tests by making a mark in the proper columns for the nutrient found to be present.

Name of Food Tested	Contains Sugar	Contains Starch	Contains Protein	Contains Fat

STRUCTURE OF HUMAN DIGESTIVE ORGANS

In order to understand many points concerning the work of the organs which deal with foods, we must first get a clear idea of the general structure of the alimentary canal and of its attached organs which secrete digestive fluids (liver, pancreas, salivary glands). Therefore we must for a time turn aside from considerations of function and study the structures of these organs.

135. The Mouth-Cavity. — (*L*) Turn your back to a window or a lamp, and with a hand-mirror reflect the light into your open mouth. Notice the *hard palate* forming the roof of the mouth-cavity. At the back of the mouth-cavity is the soft *palate*, which separates the mouth-cavity from the *post-nasal cavity;* and this cavity in turn communicates with the cavities of the nose. Take

" short breaths " and notice the effect upon the soft palate. Apply your tongue to the roof of the mouth and slowly move it backward and forward until you feel the shape, position, and texture of the hard and soft palates. Press down upon the tongue with a clean (sterile) glass rod, or the handle of a spoon, and examine the small prolongation of the soft palate which touches the tongue when that is not depressed. This is the *uvula.*

136. The Teeth. — (*L*) Examine your teeth, again using the hand-mirror, taking the following description as a guide: Beginning at the middle line at the front of each jaw, there are in order the following kinds of teeth in half of either the upper or the lower jaw: First, two chisel-shape cutting teeth (*incisors*, meaning to cut into). Next, a tooth with a more pointed edge, which corresponds to the great fangs of dogs and cats and other animals which must tear their prey; hence the name *canine* or dog-teeth. The tusks of boars and walruses are enormously enlarged canine teeth. Elephants' tusks are upper incisors. Next back of the canine tooth on each side there are in the first or " milk-set " of teeth two grinding teeth (*molars*). This makes a total of twenty teeth in the first or milk-set, which are *deciduous.* In adults there are in each half of a jaw two teeth called bicuspids (meaning two cusps or points) in place of the two molars of childhood; and back of these are three molars, often called " wisdom teeth." There are, therefore, twelve molars in adults in addition to teeth in the places occupied by the twenty teeth of the first or deciduous set, making a total of thirty-two for the adult.

The incisor teeth begin to appear in children at six or eight months of age, and the full milk-set is present after eighteen to twenty-four months. The loss or shedding of these, caused by growth of new teeth below, occurs at various times between seven and twelve years of age. The permanent teeth begin with the incisors at seven or eight years and are completed with the appearance of the molars or wisdom teeth at between sixteen and twenty years of age. The growth of the teeth through the fleshy tissue (gums) is often called " cutting teeth."

The structure may be studied by breaking open an ex-

tracted tooth, or better by studying a thin section prepared for microscopic use. There is a central cavity which, during the life of the tooth, is filled with a soft mass composed of connective tissue, blood-vessels, and nerves. This is the so-called *pulp*. The pulp-cavity extends down into each of the roots of the tooth, and at the tip of a root is a small opening through which nerves and blood-vessels enter. The hard outer part of a tooth consists of the *enamel*, and the main bulk is *dentine*, a kind of ivory. The roots of the tooth, which are buried in holes or sockets of the jaw-bone, are covered with a thin layer of bony substance, called *cement*.

137. The Tongue. — Examine with a hand-mirror. The elevations on the upper surface are *papillæ*, and nerve-fibers connect these with the brain. Their function is that of taste and touch. The tongue is chiefly muscular tissue, the muscle-fibers extending longitudinally, transversely, and perpendicularly. Can you think of any relation between such arrangements of the fibers and the possible movements of the tongue?

138. Salivary Glands. — The epithelium which lines the mouth is coated with a limited amount of fluid known as mucus, hence it is called a *mucous membrane*. But most of the fluid in the mouth is *saliva* from three pairs of *salivary glands*. On either side of the head a gland lies beneath and in front of the ear. These are the parotid (meaning beside the ear glands), and a disease affecting them is called parotitis * or mumps. A duct from each parotid gland opens into

* Notice that the ending *itis* added to the name of the organ (parotid) means inflammation or disease of the organ. Likewise, there are in common use such words as appendicitis (inflammation of the appendix of the intestines), gastritis (of the stomach), laryngitis (of the larynx), tonsillitis (of the tonsils), and many other diseases designated by adding *itis* to the name of the organ involved.

the mouth-cavity on a little elevation on the inside of each cheek opposite the second upper molars. The elevation can be seen by using a mirror and holding the cheek away from the jaw. The two other pairs of salivary glands are placed among the muscles beneath the tongue, and their ducts open into the mouth-cavity beneath the tip of the tongue. The secretions of the salivary glands will be described later when we take up their work in the digestion of foods.

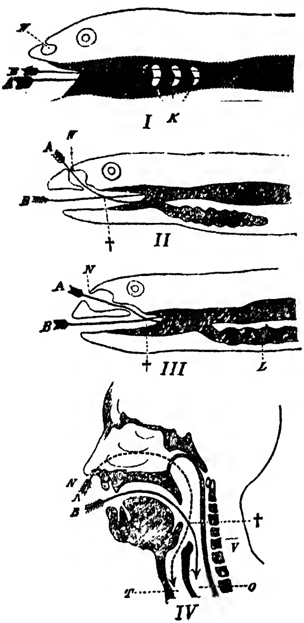

FIG. 58. Diagrams showing relations of respiratory and alimentary passages in a fish (*I*), amphibian (*II*), reptile or bird (*III*), and man (*IV*). Arrow *A* marks passage to respiratory organs; *B*, to alimentary organs; *N*, nostrils; *K*, gill-slits; *D*, alimentary canal; *L*, lungs; *O*, esophagus; *T*, trachea; *V*, backbone. (*After Wiedersheim.*)

139. The Pharynx or Throat-Cavity. — Again using the hand-mirror, notice that at the back part of the mouth-cavity muscular folds extend downward from the soft palate and bound laterally the passage from the mouth-cavity to the throat-cavity. Between these folds on each side is a round body, *tonsil.* These are the organs which often become enlarged during a "cold" in the throat (tonsillitis). They are not known to have any essential function, and surgeons frequently remove them when they become permanently enlarged.

The pharynx opens above into the post-nasal cavity behind the soft palate; and below into the esophagus and the

trachea or windpipe. Refer back to your study of the throat of the frog. Also, there open into the pharynx the Eustachian tubes from the ears. The pharynx is the passage between the nose-cavities and the trachea, and between the mouth-cavity and the esophagus, thus providing for movement of air from the nose to the lungs and of food from the mouth to the esophagus (Fig. 58).

140. **The Esophagus or Gullet** is a tube extending from the pharynx to the stomach. In the human body, and in all mammals, it extends through the diaphragm, the membrane which divides the body-cavity into thoracic and abdominal portions. In the neck the esophagus is behind (dorsal to) the trachea.

141. **The Stomach** is a muscular and greatly expanded portion of the alimentary canal or digestive tube between the esophagus and the intestine. It lies on the left side and in contact with the liver. Imagine a membrane (diaphragm) stretched across the frog's body-cavity so as to separate the heart and lungs from the stomach and liver. The human diaphragm lies in the same position; that is, the heart and lungs lie above it (anterior) and the stomach and liver lie just beneath (posterior). The end of the stomach connected with the intestine is provided with a muscular ring (pylorus) which, by opening and closing, is able to control the passage of food from the stomach to the intestine. It should be remembered that the size of a stomach, like that of a rubber bag, depends upon the amount of distension. When empty, it is contracted so that it has practically no cavity, and when much distended by food, it may hold about a half-gallon.

142. **The Small Intestine.** — The part of the intestine connected with the stomach is smaller in diameter than the extreme posterior part, and hence is called the *small intestine.*

It is very much coiled, as shown in the center of Fig. 59, and is about twenty feet long.

143. The Large Intestine is about five feet long, which is one-fourth the length of the small intestine; but the name refers to the larger diameter. As shown in Fig. 59, the large intestine extends upward, from the point of union with the small intestine, then transversely, then downward. This largest portion is often called the *colon*. The terminal or posterior portion of the large intestine, commonly called the *rectum*, is smaller in diameter than the colon part; and its external opening is the *anus*.

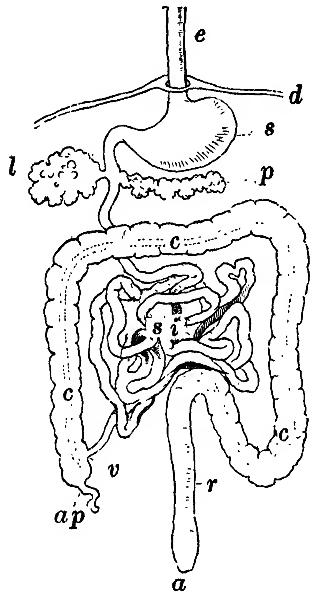

FIG. 59. Human alimentary organs. *l*, lung; *e*, esophagus; *d*, diaphragm; *s*, stomach; *p*, pancreas; *l*, liver; *si*, small intestine; *v*, valve between small and large intestine; *ap*, appendix; *c*, colon of large intestine; *r*, rectum; *a*, anus. (*From Wiedersheim.*)

Between the colon and the rectum there is an S-shaped loop (sigmoid flexure); and near the junction of the large and small intestines is the vermiform appendix (or simply *appendix*), a tube from two to four inches long and one-fourth of an inch in diameter. Its inflammation, due to bacteria, is *appendicitis*, for which the usual cure is surgical removal of the organ. It is not necessary in man; but in the rabbit and many lower herbivorous animals it is large and important in digestion.

144. Liver and Pancreas. — These two organs should be

named in the list of digestive organs, for they secrete fluids which are poured into the intestine by ducts. The position of the liver has been described in connection with the stomach. The pancreas, which in the case of some animals used as human food is called "stomach-sweetbread," * lies near the junction of the stomach and the small intestine. Its main duct (*pancreatic duct*) joins the *bile-duct* from the liver, and the fluids secreted by the two organs are poured into the small intestine a short distance from the stomach.

145. Glands. — The liver, pancreas, salivary glands, and gastric glands have been mentioned as producers of special secretions useful in digestion. Microscopic study shows that a gland is composed of a layer of epithelial cells which rest on a bed of connective tissue. In this latter tissue are blood-vessels which supply food and oxygen to the cells of the glands; and from the materials thus obtained the cells manufacture their secretions, which they discharge at the free end of the cells (*i.e.*, opposite the end where they absorb from the blood). (See Fig. 60.)

(*D*) Exhibit and describe sections of frog's stomach to show structure of simple gland. Pancreas sections show numerous tubes cut across at various angles. The cells of these tubes secrete pancreatic fluid.

THE WORK OF THE DIGESTIVE ORGANS

We have briefly considered the structure of the digestive organs, and it is now our problem to study the work of these organs, especially with reference to the preparation for absorption of the different kinds of food; *i.e.*, the nutrients. As in the frog, this digestion of foods is caused by secretions;

* The neck- or throat-sweetbread sold in meat-markets is from the thymus, an organ found only in young animals, such as calves and lambs, and lying in the anterior part of the chest-cavity close to the neck.

and in the human body these are *saliva* from the salivary glands, *gastric juice* from the glands in the wall of the stomach, *intestinal juice* from the glands in the wall of the intestine, *pancreatic juice* from the pancreas, and *bile* from the liver.

146. Mechanical Processes in Digestion. — Various movements, due to the action of muscles in the digestive organs, play *two important parts: (1) in taking food and in moving it along through the digestive tube, and (2) in separating* more or less solid food into small particles upon which the digestive fluids can act rapidly. The muscular action of the lips and jaws in taking and chewing (masticating) food is so easily observed that no description is necessary. The mastication process is important in that it results in mixing saliva with the food (see § 205, on hygiene of eating).

After mastication come the swallowing movements, which are produced by the muscles of the pharynx and esophagus. These movements are in the beginning voluntary (*i.e.*, under control of the will); but it is well known that when food has started down the esophagus, the muscular walls of that organ contract (narrow the diameter) involuntarily, and force the food into the stomach. The fact that food is forced down and does not run because of gravity explains how an acrobat can perform the feat of drinking water while standing on his head. Horses and cows are examples of animals which regularly drink and eat with the mouth-cavity much lower than the stomach.

(*D*) Take a piece of soft rubber tubing about two feet long, suspend vertically, plug the lower end with a cork, and fill with water. Now, begin at the plugged end and squeeze the tubing between a thumb and finger and then move your hand upward so as to contract the tube in succession. It is evident why the water goes up-hill in the tube. Similarly, the muscles which are in the walls of the esophagus contract in succession from the pharynx toward the stomach and force the food along the esophagus.

The muscle-fibers in the walls of the stomach are arranged transversely, longitudinally, and obliquely. The part of the stomach next to the esophagus contracts and steadily presses upon the contained food; but the posterior half undergoes a series of wave-like constrictions. The result is that the food is broken up into smaller masses and well mixed with the digestive fluids. These movements have been studied by feeding dogs and cats with bismuth subnitrate, a drug which physicians often prescribe to allay gastric irritation. This drug mixes with the food in the stomach and renders the whole mass so opaque to the X-rays that the shape of the stomach is easily seen with the aid of a fluoroscope, and photographs can be made similar to those often taken of the skeleton within the body.

From time to time the pylorus opens, allowing liquid foods (often called chyme) to pass into the intestine. As a rule, the large masses of solid food are held back in the stomach.

The movements of the intestine consist of constrictions. These sometimes appear in series at certain points, and then next at the points which are halfway between the first constrictions. This causes a thorough mixing of the foods with the digestive fluids. Another form of constriction which occurs at intervals moves along the intestine and forces the contents towards the large intestine. The above experiment with rubber tubing illustrates this type of construction. Such movements are known as *peristaltic contractions.*

147. Why Foods must be Digested. — We have seen in our study of the frog that foods must be prepared so that they may be absorbed through the lining membranes (epithelium) of the digestive organs into the blood. In other words, foods must be capable of osmosing through membranes; and most foods, taken into the mouth, are not

ready for this process. Glucose sugar and common salt dissolve in water, and are practically the only common foods which can be absorbed without digestion. Even milk, our most common liquid food, contains droplets of fat too large for absorption which must be dissolved in preparation for absorption. Moreover, milk becomes coagulated in the stomach, and the clot must be digested.

Microscopic Examination of Milk. — (*D*) Mount a drop of milk on a glass object-slide. Examine (1) with low-power, (2) high-power objective. Note the droplets of fat. These are lighter than the water of the milk; and, like oils in general, rise to the surface when milk stands, forming the concentrated layer of fat which we call *cream*. When the cream is shaken or agitated, as in a churn, these fat droplets fuse together into larger masses of fat, which we call *butter*.

Since digestion practically means the preparation of foods for absorption, it is convenient to study the action of the various digestive secretions (saliva, gastric juice, bile, and pancreatic fluid) by adding them to foods in test-tubes; and after allowing time for a change, try for osmosis of the food through membranes, such as fish-bladder or parchment. There are good reasons for thinking that any food which will osmose through a dead membrane will also be absorbed under conditions which exist in the linings of the stomach and intestine. Hence any digestive changes which will prepare foods in test-tubes for osmosis will serve to illustrate the changes which take place inside the living alimentary canal. But not all the digestive processes can be illustrated by test-tube experiments, for the living digestive organs cause some changes in foods which cannot be imitated in the lifeless conditions in test-tubes. However, it is possible to perform a number of experiments which will throw much light on the various secretions of the alimentary canal with regard to

their part in the digestion of the various kinds of foods. We shall consider the digestive processes in the order in which foods come in contact with the secretions in passing from the mouth-cavity through the esophagus into the stomach, and thence into the intestine; this means contact, in succession, with the salivary, gastric, intestinal, pancreatic, and hepatic (liver) secretions.

148. Digestion by Saliva. — The fluid secreted by the salivary glands consists chiefly of water and an enzyme called ptyalin, which is very similar to the diastase of plants. The dry ptyalin may be purchased from chemists, or saliva may be collected in a test-tube (when one chews a piece of rubber or gum it is secreted rapidly). The work of saliva is the digestion of starch to a kind of sugar, which is absorbable. This is illustrated by the following experiments: —

(*D*) Make some thin starch paste, by heating starch in water. Notice that the resulting fluid is not clear, but opalescent. Place a small quantity of the paste in a test-tube and add a few drops of iodine solution. Note the color.

(*D*) Place some of the paste in a small bag made from a piece of gold-beaters' membrane, or fish-bladder, and suspend the bag so that it dips into water in a small tumbler or beaker. Or put some of the paste in an osmose apparatus.* After allowing an hour or two for osmosis to take place, transfer some water from the tumbler into the test-tube, and add some iodine solution. Compare with test of starch as directed above. Is there evidence that starch osmoses through a membrane?

(*D*) Along with the above, test grape-sugar or corn-sirup by placing in water inside a bag or in the tube of the osmose-apparatus. Wait the same time as in the case of the starch, and test water in the tumbler with Fehling's reagent (§ 66). Does the sugar osmose?

(*L*) Mix some starch scraped from a potato in a drop of cold water on a glass slide, put on cover-glass, and examine with low power of microscope. Note the appearance of the starch-grains. Now remove the slide from the microscope and heat slowly over an

* Described in "Teachers' Manual of Biology," § 398.

alcohol- or a gas-burner until the water begins to steam. Examine again with the microscope, and note the broken starch-grains. These broken grains mixed with the water form starch paste, and the opalescent appearance of the thin paste is due to the numerous particles of starch floating in the water. Examine starch scraped from a baked or boiled potato.

(*D*) Place some thin starch paste in each of two test-tubes. Add to one tube (No. 1) a few drops of clear saliva (filtered through coarse filter-paper). Tube No. 2 has only paste. After twenty to forty minutes note the appearance of the paste in the tubes, especially with regard to opalescence. Pour a small quantity from tube with the saliva (No. 1) into a clean test-tube, and add a few drops of iodine solution. Is starch present?

(*D*) Into another tube pour some starch paste from tube No. 1, and into still another pour paste that has been acted upon by saliva in tube No. 2. To each of the tubes apply Fehling's test. Results? Conclusions? Do these experiments suggest why a dry starchy cracker becomes sweet to the taste after being held in the mouth for some time?

(*D*) If time permits, prepare three tubes with thin starch paste. To No. 1 add boiled saliva; to No. 2 add normal saliva, and also a few drops of acid (vinegar will do) to make the paste slightly acid (test with blue litmus-paper); and to No. 3 add saliva, but keep the tube standing in a tumbler filled with finely cracked ice. After twenty to forty minutes test for starch and sugar as in above. What do these experiments show regarding (1) effect of boiling saliva, (2) effect of acid, (3) effect of low temperature? Boiling and low temperature have the same effect on all the secretions of the stomach, intestine, and pancreas.

(*D*) In order to show that saliva changes starch into sugar capable of being absorbed (*i.e.*, osmose through a membrane), take some starch paste which has been acted upon (digested) by saliva for two or three hours, place in a membrane bag or osmose-apparatus, allow a half-hour for osmose, then test water in tumbler for sugar.

The above experiments simply prove that saliva digests starch to a sugar; and that while starch does not osmose, the sugar formed from starch does. Saliva, then, prepares starch for absorption into the blood which flows in blood-

capillaries beneath the lining membrane (epithelium) of the alimentary canal, especially abundant in the stomach and intestines. The sugar derived from starch osmoses through the epithelium into the blood, just as it is demonstrated by the above experiments that it will osmose through the dead membrane of the osmose-apparatus.

It is evident that the above experiments do not prove anything regarding the action of saliva on other nutrients. If time permitted, we might try similar experiments with proteins and fats, using these nutrients in place of starch, and, of course, applying the appropriate tests (§ 129). Such experiments have been performed many times by physiologists, and their conclusion is that saliva has no digestive power for foods other than starch.

No simple experiment will show that there is in saliva a substance (ptyalin) which causes the digestion of starch, but chemists have proved it to be present, and the cause of the action of saliva. Moreover, it has been shown to be an enzyme, because it acts by its presence, without entering into the sugar formed, and a very small amount of it can digest a large quantity of starch.

The amount of starch food which will be digested in the mouth-cavity depends upon the length of time it is held there. Hence, prolonged mastication is advisable. It has been demonstrated within recent years that saliva continues its action on starch for some minutes after the food reaches the stomach, or until the acid gastric juice stops the action.

149. Digestion by Gastric Juice. — Physiologists have found that the human stomach secretes from five to ten quarts of gastric juice in twenty-four hours. This secretion consists chiefly of water containing a small amount of hydrochloric acid and three enzymes — pepsin, rennin, and lipase. The last named seems to be of most importance after food

reaches the intestines. The action of pepsin and of rennin is most easily demonstrated. Pepsin may be extracted by soaking stomach-membranes in glycerine, but the commercial extract sold at drug-stores is most convenient for experiments. Rennin is especially abundant in the stomachs of calves, and is sold in grocery and drug stores under the names of "liquid rennet" and "junket tablets."

Numerous experiments by physiologists have proved that gastric juice digests proteins, curdles (coagulates) milk, dissolves some minerals in foods, and digests a small amount of fat, but it has no effect upon starch. In this course, we have time for only a few experiments which illustrate some of these points.

The Action of Pepsin on Proteins. — (*D*) (1) Make some albumen-solution by mixing white-of-egg in cold water, fill a test-tube half full, add some dry pepsin or glycerine extract of pepsin, add enough hydrochloric acid to make the mixture slightly acid to litmus-paper, place the tube in a warm place near a stove or radiator, or in a "fireless cooker" or bucket of water heated to 37° C. (98 F.) and protected from cooling rapidly. After from three to ten hours, pour the contents of the test-tube into a membrane bag or osmose-apparatus and suspend in pure water. (Start the next experiment at this time.) Allow an hour for osmosis. Test the water for proteins (§ 129), using Millon's reagent. Have proteins gone through the membrane into the water?

(2) Pour some fresh *undigested* albumen-solution into a membrane bag, and after an hour test for osmosis as in above experiment. Does this albumen osmose? What conclusion is to be drawn concerning the effect of pepsin and acid on the particular protein used in these experiments?

If time permits, *other proteins* may be tested in the same way. Try a hard-boiled egg grated or minced into fine particles, shreds of lean meat, or cheese. Also, the acid may be omitted, in order to show that pepsin alone will not digest proteins.

(*D*) The action of the *rennin* may be illustrated by adding some commercial liquid rennet or junket tablets to milk. Place some of

the curds on filter-paper, wash with water, place in a test-tube with some water, add strong nitric acid, heat. What nutrient is abundant in the curds? Pepsin and acid will digest them.

Summarizing, gastric juice can digest proteins, coagulate the proteins of milk, and then digest them, and digest a small amount of fat; but it does not digest starch. Fat meat breaks up extensively when kept for some hours in gastric juice, but only the protein walls of the cells have been digested, allowing the contained oil to escape undigested.

Fat-Cells. — (*D*) Place a small piece of fat meat or suet in a drop of glycerine on an object-slide, and with a pair of needles tease the meat into as small particles as possible. Put on cover-glass, and examine with low and high power of a microscope. Note the spherical cells filled with fat, which may be in the form of needle-shaped crystals at the ordinary temperatures. If a small piece of fat meat be soaked for a time in ether to dissolve the fat, and then placed in iodine-eosin or other stains, the nuclei of the fat-cells will be stained.

150. Digestion in the Intestine. — While the gastric juice has power to digest protein foods, the fact is that most of them do not remain in the stomach long enough for complete digestion ready for absorption. At intervals, the muscular ring of the pylorus relaxes and allows partially digested foods to escape into the intestine, there to undergo final digestion and absorption into the blood. This food which escapes into the intestine from the stomach is water containing (1) much starch not digested by the saliva, (2) sugar which was eaten as such and much of the sugar formed by the digestion of starch by the saliva, (3) dissolved proteins digested in the stomach, (4) many particles of undigested proteins, and (5) fat in liquid (oil) condition. The *work of the intestine* is to complete the digestion of the proteins, fats, and starch; and to absorb the products of digestion into the blood and lymph.

151. Secretions in the Intestine. — These are formed by the pancreas, the liver, and the glands of the intestinal walls. The pancreatic secretion contains enzymes able to digest any kind of food, and consequently any food not made ready for absorption while in the stomach is digested by the enzymes poured into the intestine. The final result is that the starch, proteins, and fat which enter the intestine undigested are prepared for *absorption.* For this work the intestine is specially adapted, because of the numerous delicate processes (called *villi,* singular is *villus*) which extend from the lining membrane (see Fig. 60). These are richly supplied with blood- and lymph-vessels, into which digested food is absorbed rapidly.

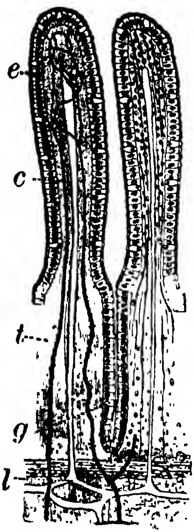

Fig. 60. Diagram of two villi from small intestine. *c,* blood-capillaries; *e,* epithelium covering villi; *g,* gland; *l,* lacteal, a lymph-vessel; *t,* connective tissue. (*After Hardy.*)

152. Details of Digestion in Intestine. — (Optional) The bile from the liver, the secretion from the glands in the walls of the intestine, and the pancreatic secretion are alkaline, and quickly change the acid food which arrives from the stomach. Of the pancreatic secretion, the enzyme called amylopsin acts like the ptyalin of the saliva and digests starch to sugar; the enzyme called trypsin acts on proteins much the same as pepsin does in the stomach; and the enzyme lipase (or steapsin) changes fats to glycerine and fatty acid. Glycerine is absorbable. The fatty acid easily combines with the alkaline substances in bile and intestinal juice and forms a kind of soap that is absorbed by the lacteals, which are exten-

sions of lymph-vessels into the villi. Since the pancreatic secretion is able to digest rapidly the three kinds of food, it is by far the most important digestive secretion.

Bile, from the liver, does not itself digest any food, but it has been shown that fats are digested and absorbed better when bile is present.

The intestinal juice, from the glands of the intestine, has a number of enzymes of which the most important change cane-sugar, milk-sugar, and malt-sugar into glucose or similar sugars.

(*D*) It is possible to demonstrate the effect of pancreatic secretion upon proteins and starch by performing experiments similar to the previous ones (§§ 148 and 149) with saliva and gastric juice. See the "Applied Biology," § 402.

153. Summary of Digestion and Absorption of Foods. — Grape-sugar dissolved in water may be very slightly absorbed in mouth-cavity and esophagus, some in stomach, but chiefly in intestine. Cane and some other sugars are changed before absorption in the intestine.

Starch. — Some digested to sugar (maltose) in mouth-cavity and in stomach by saliva, but chiefly digested to maltose in intestine by amylopsin of the pancreatic secretion. Resulting sugar may be absorbed as stated for sugar above.

Proteins. — Digested to absorbable form in stomach by pepsin and in intestine by pancreatic secretion. Absorbed to slight extent from stomach, but chiefly from intestine. Milk proteins are coagulated in stomach by rennin as a special preparation for digestion by action of pepsin, or later by pancreatic secretion.

Fats. — Chiefly digested in the intestine by lipase of pancreatic secretion, aided by bile and intestinal juice. Slightly digested by lipase in the stomach. The protein part of

tissues containing fat (*e.g.*, bacon or suet) is digested away in stomach by pepsin, thus freeing the liquid fat.

Mineral foods. — Those that, like common salt, are soluble in water require no change. Others present in various animal and vegetable foods which we commonly use are easily dissolved in the acid gastric juice. All the mineral foods are ready for absorption when dissolved in water.

154. Why Foods are Cooked. — The subjection of foods to great heat in steaming, boiling, baking, and roasting has several useful effects: (1) The cell-walls and starch-grains of vegetable foods are broken, thus preparing for action of digestive fluids. Raw starch inside plant cell-walls is difficult to digest. (2) Parasites (such as tapeworms, trichinæ and disease-producing bacteria) are killed. (3) Easily-digested gelatin is formed from the abundant connective tissue of animal flesh; and muscular and other tissues are softened and loosened so that they can be readily acted upon by juices in the stomach and intestine. Raw protein is more easily digested than when cooked; but the last two advantages named above make it desirable to cook meats. (4) Most cooked foods are more palatable.

Beef placed in cold water and slowly heated loses to the water certain substances, forming beef-tea. This has little food value; but is pleasant and stimulating. Meat dropped into boiling water coagulates on the surface and hence little material is lost to the hot water. Roasting, broiling, boiling, and steaming best prepare foods for digestion; while frying in lard, butter, or oil causes the oily materials to cover the food and thus render the penetration of digestive juices more difficult. In general, a similar result comes from any heating of starch and fat together; and hence pastries, such as pie-crust, are more indigestible than would be the same amount of the ingredients taken into the stomach

without heating together. Various methods of making starchy foods porous, such as the action of baking-powder and yeast, favor rapid penetration by the digestive juices.

155. Transportation of Digested Food to All Cells. — It has been stated in a general way that foods are required by all the living cells of the human body. The study of digestion and absorption has shown how foods get into the blood and lymph, and now we want to know *how foods get into the cells.* This requires (1) that blood and lymph should be moved from the capillaries in the walls of the digestive organs to the capillaries in all the other organs of the body, and then (2) absorption from the blood and lymph by cells which need food. Before one can understand how food is transported to all parts of the body, it is necessary to make some study of the general plan of structure of the organs concerned with the movement of blood and lymph, and also of the nature of these two liquids. Hence our next lesson deals with these topics.

BLOOD AND LYMPH

156. Structure of Human Blood. — If examined with the microscope, blood is found to be a liquid, called plasma, in which float numerous small bodies, *blood-corpuscles* or *blood-cells.* About 90 per cent of the plasma consists of water, which has been absorbed from the digestive organs, and more than 9 per cent consists of absorbed foods. There are also in the blood some excretions which have been absorbed from cells and are on their way to the excretory organs where they will be eliminated.

In human blood there are two kinds of corpuscles or cells visible with the microscope; namely, the red and the white (Fig. 61). The red ones are bi-concave discs, about $\frac{1}{3200}$ of an inch in diameter. They are often seen in rolls like piles

of coins. The number of them is astounding, for there are about five million in a cubic millimeter of blood. (A millimeter is approximately $\frac{1}{25}$ of an inch; compute how many red corpuscles in a cubic inch of blood.) In the diseased condition known as anæmia, which is characterized by whiteness of the skin, the number of red corpuscles is greatly reduced.

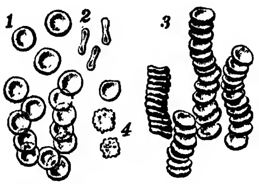

FIG. 61. *1*, red blood-corpuscles; *2*, same in edge view; *3*, in rolls; *4*, white blood-cells.

The red color of these blood-cells is due to a substance called *hæmoglobin*, which is most important in the blood's work of carrying oxygen to the cells of the body.

The *red corpuscles* of man and other mammals have no nuclei, except in embryonic stages; but all lower vertebrates — birds, reptiles, amphibia, and fishes — have nuclei in all red corpuscles, even in the adult animals. Scientists have not yet found any reason for this difference.

It is also interesting to know that red corpuscles are constantly being formed in the red marrow of bones.

(*D*) Obtain a long bone from a meat-market, break it open, and examine the marrow.

The *white corpuscles* are irregular in shape, because they move spontaneously like an amœba (§ 114). In human blood they occur in the proportion of one white to 500 of the red cells. They are exceedingly abundant in blood taken from any inflamed place, such as a boil, pimple, or wound. Like an amœba, which they resemble, although there is no connection as to origin, the white cells can ingulf (" eat ") small particles, such as

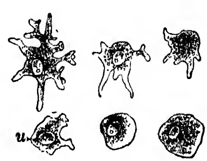

FIG. 62. Various shapes of a white blood-cell.

bacteria, by the flowing of the protoplasm around the object. It is believed that their work or function is that of destroying bacteria and particles of dead cells. This explains why they are abundant in such places as boils and abscesses. The material known as pus, which exudes from such centers of inflammation, consists largely of white corpuscles and pieces of the dead cells of the inflamed tissue.

(*D*) Examine a drop of human blood spread on an object-slide and protected with a cover-glass. A drop may be obtained by wrapping a piece of string tightly around the second or third finger near its end and then pricking the skin with a needle which is first made sterile by passing several times through a flame. One small drop of blood should be mounted on an object-slide and a second small drop should be placed in a drop of normal salt solution (common salt 7 grams in a liter of water, which gives 0.7 per cent). The red corpuscles appear faint yellow in color when not in masses. They have no nuclei. The rarer white cells are difficult to find, but may be located by turning the micrometer screw about half a revolution so as to throw the red corpuscles slightly out of clear focus, and then a few white cells may be seen as glistening points of light in the field. They are somewhat larger than the red cells.

Blood from a frog, fish, or bird, or permanent preparations of these, are interesting for comparison with human blood. Nuclei are in the red cells of these animals and the cells are much larger than those in human blood.

Blood from an earthworm, crayfish, insect, or other invertebrate animal has only white cells.

157. Coagulation of Blood. — Every one knows how blood will flow from a cut for a time and then stop because some of it has thickened into a jelly-like mass, which closes over the cut and forms a scab. This process of thickening is known in physiology as *coagulation*, or clotting. Examination of blood allowed to clot in a drop of normal salt solution will show that coagulation is due to the formation of delicate fibers which bind the corpuscles into a semi-solid

mass. These fibers are composed of a substance called *fibrin*, which is a coagulated form of a protein called fibrinogen. This is dissolved in the plasma of the blood and becomes hardened into threads when blood escapes from a blood-vessel. If fresh blood of any animal be stirred with a feather, the fibrin will form on the feather and the defibrinated blood will not coagulate, thus proving that the formation of fibrin causes coagulation.

The use of coagulation is obviously to prevent excessive bleeding. If blood did not coagulate quickly, a slight injury to even a small artery might cause the death of animals, or of men before surgical aid could be secured.

158. Lymph. — This is a liquid very much like blood, but without red corpuscles. It is in part blood-plasma which has passed through the capillaries into the very small spaces which exist between the cells in all tissues. Thus lymph comes into direct contact with the cells, giving to them food and oxygen, which are dissolved in blood-plasma, and receiving from the cells some excretions, especially water. These small lymph-spaces between the cells are united together into larger lymph-capillaries, which in turn connect with the large lymph-vessels. These pour their lymph into the veins in which blood goes back to the heart. Lymph, then, is in part plasma which passes from blood-capillaries into lymph-spaces, receives some water and other secretions, then flows into lymph-capillaries, and through larger vessels back into the blood-veins near the heart. The arrangement of blood and lymph-vessels in any organ might be compared with the irrigation systems for watering agricultural land. The blood-capillaries correspond to the ditches from which water seeps out into the spaces between particles of soil. These spaces in the soil correspond to lymph-spaces, while the lymph-capillaries and larger tubes correspond to the

drain tiles which carry excess water away from irrigated soil. In short, the lymph-spaces in any organ constitute a sort of combined irrigation and drainage system for cells which are not directly reached by the main canal system of the blood-capillaries.

Lymph contains white corpuscles (Fig. 62), which are able to pass through the walls of blood-capillaries into lymph-spaces. They are also formed in great numbers in the *lymphatic glands* through which lymph flows on its way back to the blood in the large veins.* In fact, the white cells in blood are lymph-cells washed into the blood from the lymphatic glands. The spleen and the tonsils are examples of large lymphatic glands, and there are hundreds of small ones in various parts of the body.

CIRCULATION OF THE BLOOD

159. Need of Movement of Blood. — In order that blood may serve its purpose as a distributor of food and oxygen to the cells and as a remover of excretions from cells to the excretory organs, it is necessary that it should be kept constantly in motion. This is accomplished by the circulation of the blood from the heart through the arteries and capillaries into the veins, which conduct it back to the heart. That the blood thus goes around in a circuit was unknown until 1621, when Dr. Harvey, of England, proved that in man and other vertebrates the blood always flows in one direction from the heart in blood-vessels, and that these are so arranged that blood ultimately comes back to the heart, *i.e.*, makes a complete circuit. This circulation is remarkably rapid; it is believed that blood goes from the heart through the capillaries in such a distant organ as a foot and returns to the heart in about half a minute. (How many times would the blood complete its circuit in a day?)

160. Structure of the Heart. — (*D* or *L*) Procure from the market a sheep's heart with the lungs attached, and with the membrane (*pericardium*) surrounding the heart. Insert a large tube in the trachea and inflate the lungs by blowing air into them. Note the relation of lungs and heart. Carefully dissect away (with forceps and scissors) the fat which adheres to the heart, taking care not to cut off any arteries or the thin-walled veins. It is best to stuff the veins with cotton or insert a small roll of paper.

The general form and external structure of the sheep's heart is similar to that described and illustrated for the human heart in many books on anatomy and physiology. Examine pictures in such books; note positions of the two *auricles* and two *ventricles* of the sheep's heart. Notice that a probe (*e.g.*, a blunt stick or glass rod) inserted into a vein enters an auricle. The connection of the arteries with the ventricles can be seen later (next paragraph). Cut across the heart transversely about an inch from the pointed end (apex). This will open the two ventricles. The left one is a rounded cavity, the right is crescentic in outline. Note the relative thickness of the muscular walls of the two ventricles. Now, take a blunt stick about the size of a pencil, and inserting it into the left ventricle, probe carefully until it emerges out of the largest artery. This is the *aorta*, whose branches are arteries leading to all the organs except the lungs. Insert a similar stick into the right ventricle and out through its artery. This is the *pulmonary artery*, whose branches conduct blood to the lungs.

The *action of the valves* in the aorta or pulmonary artery in preventing blood from flowing back into the ventricles can be demonstrated on a heart with the apex removed, as follows. Insert a large glass tube (about $\frac{1}{2}''$ or $\frac{3}{4}''$ caliber) into one of these arteries held upright, and fill it with water. Or connect the artery with a large funnel. If the valves are still in good order, the water will remain in the tube or funnel.

To demonstrate the action of the auriculo-ventricular valves, cut away the auricles from a heart with the apex removed, and then plunge it, with the ventricle held downward, into water so as to float the valves into the closed position.

Slit open the aorta to expose its valves (semi-lunar); and also cut the side of a ventricle to show attachment of the auriculo-ventricular valves.

161. The cause of circulation is the constant, rhythmic beating of the heart, which is a muscular force-pump. Its general plan of structure is illustrated by an ordinary rubber bulb such as is used for atomizers and syringes. In such a bulb there are two valves arranged so that when the bulb is filled with water and then compressed, one valve (inlet) closes and prevents the water from flowing outward, the other valve (outlet) remains open and allows the water to escape into the outlet tube. Then if the bulb be allowed to expand, the outlet valve is closed by the back pressure of the water in the outlet tube, and water rushing in from the supply tube opens the inlet valve. The next compression will again arrange the valves as first described above. (Draw diagrams to illustrate positions of valves and with arrows show direction of flow through a two-valved bulb.)

In a similar manner, there are valves arranged in the heart in two places, one valve to prevent a flow of the blood back into the veins (inlet) when contraction occurs, the other to prevent the return flow from the arteries (outlet tube) when relaxation or dilation takes place. And, as can be easily demonstrated with a rubber bulb having one inlet and one outlet valve, repeated contraction and expansion will cause fluids to flow through always in the same direction, which is determined by the arrangement of the valves. Hence, the blood circulates because the heart is a pump with valves so arranged as to force the blood to flow in only one direction, out through one valve, and thence around through tubes which lead back to the inlet valve.

There are valves (Fig. 63) in all but the largest veins and they aid in the circulation of blood especially when contracting muscles press upon the veins between two valves. The region so pressed acts like a syringe-bulb which has outlet and inlet valves, each compression driving blood towards the heart.

162. Heart a Duplex Pump. — Like some pumping-machines with two pumps united side by side, the heart of man and of other mammals is double. To illustrate it correctly with the rubber bulb mentioned in the above paragraph, it would be necessary to place two bulbs side by side. One bulb would represent the right and the other the left ventricle of the heart. The right ventricle pumps blood into arteries which extend to the lungs, and the left pumps blood to all the other organs. Moreover, the blood pumped from the

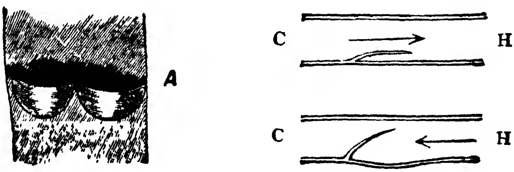

FIG. 63. *A*, pocket-like valves of veins. Arrow pointing from *C* to *H* shows valves opening towards the heart, while the lower figure shows how the valve would float up and close if blood started to flow backward towards the capillaries through which it came.

right side of the heart to the lungs comes back in veins which connect with the left side, and the blood from the left ventricle comes back to the right side of the heart. In other words, the two sides are constantly supplying each other. Both right and left ventricles contract at the same time, the right one forcing blood into the lungs, and thence into the left collecting chamber (left auricle), while the left ventricle forces blood into all other organs, from which the blood returns to the right collecting chamber (right auricle).

It is evident from the above that the two sides of the heart must pump equal amounts of blood, for they beat (contract) together, and each supplies the other with blood. Why then should the walls of the right ventricle be so much thinner than those of the left? The answer is that the right ventricle

meets with less resistance in pumping blood to the lungs than does the left ventricle which pumps to all the distant parts of the body. It is a familiar fact that a force-pump that empties water into a near-by bucket is easier to work than one connected with a long line of pipe or hose.

163. Pulse. — The well-known throbbing movement of certain arteries (as in wrist and in temple) which are near enough to the skin to be felt with the fingers, is due to wave-like expansion of the arterial walls which begins when the contracting ventricle forces its contained blood into the already-full arteries. This causes expansion first of the elastic aorta and then in succession of all the arteries, over which a wave-like expansion passes as the amount of blood equal to that discharged by the ventricle is moved onwards towards the capillaries.

(*D*) It may be imitated with a soft rubber tube (5 or 6 feet long) connected to a small pump or syringe-bulb. While pumping water, steadily press upon the tube with a finger, and note the pulsations which follow each stroke of the pump. Then insert a glass tube with a small opening into the end of the rubber tube, and pump rapidly enough to make the jet of water a steady stream. Now note that the rubber tube is somewhat expanded under internal pressure, and that the " pulse " is still discernible.

This simple experiment imitates the conditions in arteries. Their walls are elastic, the small arteries and capillaries exert resistance and prevent the sudden flow of blood through them (just as the small opening at the end of the rubber tube does); the blood forced into the elastic arteries expands them, and their recoil steadily forces blood through the capillaries. The effect of the elastic walls of the arteries is the same as that of a long rubber hose attached to a force-pump, and of the elastic air compressed in the air-chamber of pumps which force water directly into iron pipes. If the

arteries were rigid like glass or iron, there would be no pulse, and blood would be sent in sudden spurts through the capillaries.

(*D*) To illustrate this, replace rubber tube in experiment above with a tube of glass of same caliber and length. (Any desired length may be made by joining chemical glass tubing with short pieces of rubber tubing.) When the pump is worked as before, jets of water will issue from the end of the glass tube, no matter how large or small an opening is present. The same thing happens in an ordinary force-pump, and in order to get a steady flow of water in our city water systems an air-chamber near the pump is used. (Explain action of air-chamber.) Obviously the elastic arteries afford a simple way to get the effect of an air-chamber on a force-pump; namely, a steady flow of fluid through the small branches (capillaries) of the system of tubes.

The next section deals with still another advantage of elastic arteries.

164. Regulation of Blood Flow. — It often happens that an increased activity of the organs demands a greater movement of blood for carrying more food, oxygen, or excretions; or a decreased activity demands a lessened circulation. In short, there is need of a regulated blood flow from the heart through the organs. This is brought about in two ways: (1) by control of the heart, and (2) control of the arteries.

Control of the heart is through the nervous system, certain nerves carrying to the heart impulses or "messages" which increase the rate of its beat, while other nerves inhibit or diminish the beat.

Control of the arteries is likewise the function of certain nerves. The small elastic arteries in all living organs are usually somewhat constricted, thus offering some resistance to arterial flow, and keeping up a continuous stream through the capillaries and veins back toward the heart. This constriction or reduced caliber is produced by a contraction of

the muscle-fibers in the walls of arteries, and this contraction is under control of nerves.

When an organ needs an increased blood-supply (*e.g.*, the stomach in digestion), it may be obtained by a nervous reaction leading to a relaxation of the muscular walls of the smaller gastric arteries, thus enlarging their diameter. Similarly, the application of hot water or mustard to the skin leads reflexly to an increased blood flow; but cold water produces the reverse effect of contraction of the arteries and a reduced circulation of blood. (See bathing, § 208. Also see account of heat regulation by the skin, §§ 197, 203.)

With the exception of the heart itself and the lungs and brain, the larger organs of the body are well supplied with nerves able to regulate the size of the smaller arteries and consequently the amount of blood-supply.

Whenever there is a great increase in caliber of the blood-vessels, the heart beats faster in order to keep up the pressure. In this way, certain drugs used by physicians may increase the action of the heart by reducing the pressure in dilated arteries.

USE OF FOODS IN THE CELLS

165. We have now studied the preparation and distribution of foods to the cells. Naturally we now ask questions regarding the use which the cells make of the food supplied to them. In studying the frog, we have noted that foods are used in part for supplying energy and in part for repair and growth. In order to apply this fact to human life we need to consider more carefully the kinds of foods in relation to the supply of energy and materials for repair and growth. Are all foods equally valuable? Should we give any attention to the selection of our daily diet? Such questions are

common nowadays, and show that there is a widespread popular interest in the uses of various foods. We shall first consider foods for energy (especially heat and muscular work), and later, foods for repair and growth. This is only a convenient division into topics, for some foods can serve all purposes.

166. Energy and its Conservation. — Some general considerations regarding energy will make clear the use of foods as a source of power in the human body.

We are familiar with the fact that stored energy in coal may be changed into mechanical energy by a steam-engine; and this into electrical energy by a dynamo; and the electrical energy into heat energy by an electric-stove, or into light by an electric-lamp, or into mechanical energy by a motor. Thus the stored energy of coal may be changed into various other *forms of energy* which are known as mechanical energy, heat, light, and electricity.

One of the important discoveries of the last century was that in such changes no energy is lost to the world. At first this statement will be puzzling to one who has read that 85 per cent of the energy stored in a ton of coal does not appear in the work of the best steam-engines in common use, and hence seems to be lost energy. Also, there appears to be a loss in transforming to electricity, for a 20-horse-power steam-engine driving a dynamo cannot generate enough electricity to drive a 20-horse-power electric-motor. However, this loss of energy from the practical standpoint is, after all, not a real loss, for the same amount of energy remains in the universe. This could be proved by placing a small steam-boiler and its furnace, an engine, a dynamo, and a motor together in a room with walls that would prevent loss of heat. Then if some fuel were burned and the machinery set to work, generating steam and electricity,

the explanation of the apparent loss of energy would be found chiefly in the heat given off to the air in the room. Adding this to the energy of the engine, dynamo, and motor, the sum would equal the amount of energy which a chemist can demonstrate by burning the same amount of coal in a calorimeter (§ 168). In short, from 85 to 90 per cent of the energy stored in coal is given off from the machinery as heat, 10 to 15 per cent appears in the mechanical energy of the steam-engine, some less in the electrical energy of the dynamo, still less in the energy manifested in the electric-lamp, heater, or motor. But each apparent loss is represented by heat given off to the surrounding air. The fact is, then, that energy can be transformed from one form into another without loss, or without reducing the amount of energy in the universe; that is, energy cannot be destroyed. The total amount of energy in the universe is always the same.

Another important discovery is that energy is not being created anywhere. The most wonderful machines can do nothing but transform energy. For example, the steam-engine is a machine for changing heat energy into motion or kinetic energy. A water-wheel changes the potential energy of water stored at an elevation into motion. A watch changes into motion the energy stored in a wound-up spring. An electric-battery changes the energy stored in chemicals into electricity. And so we might go through the whole list of known physical changes in the universe, and in each case find evidence that transformation of energy, and not destruction and creation, is constantly occurring in the universe. Science has found no positive evidence concerning either creation or destruction of energy in all its forms.

The facts regarding changes of energy are now embodied in the *Law of Conservation of Energy*, which is, that energy

can be transformed from one form into another, but cannot be created or destroyed.

One of the most interesting phases of science study is that of the changes of energy as presented in the science of physics. The law of conservation of energy has numerous practical applications in machinery. For example, a physicist would never spend his time in trying to invent a "perpetual-motion machine," for that would be completely opposed to the established law of conservation of energy.

167. Energy of the Human Body. — This is manifested externally in the form of heat, and muscular and nervous activity. The source of this energy is the stored or potential energy of food, and numerous experiments have demonstrated that the law of conservation of energy applies to the human body (and all other living things), just as it does to a steam-engine. Food for the human engine and fuel for a steam-engine are both necessary because they contain stored energy. In both cases the original source of the stored energy was sunlight, which green plants utilized in making carbohydrates.

168. Foods for Energy. — The energy value of the three important nutrients (proteins, carbohydrates, and fats) is easily computed by chemists. Samples of such nutrients are dried and then quickly burned inside an apparatus known as a *calorimeter* (heat-measurer), and the heat thus generated is measured in terms of the amount of heat necessary to raise 1000 grams of water one degree Centigrade. This amount of heat is a *calorie*, the standard unit for heat measurements;* and since heat may be converted into other forms of energy (§ 166), it is convenient for measuring the total energy of foods.

* Some authors of textbooks use the "small calorie," which is the amount of heat necessary to raise one gram of water one degree C. It has an advantage in measuring small quantities of heat less than enough to raise 1000 grams of water one degree.

The heat value of a gram of food measured in this way is as follows: for dry protein, about 5.6 calories (*i.e.*, 5600 grams of water 1°); for carbohydrates, about 4.1; and for fats, about 9.3. It has been shown by a method described in the next paragraph that a man or a higher animal obtains about 9 calories from fats, and 4 from carbohydrate foods; while protein is not completely oxidized in the living body, so that one gram of protein gives only about 4 calories of the 5.6 it contains. Obviously, proteins are not economical as foods for heat or muscular energy, while carbohydrates and fats give almost as much energy in the body as when they are completely burned in a chemist's calorimeter. The chemical result for fats and carbohydrates is the same in both cases, for these foods produce carbon dioxide (CO_2) and water (H_2O) in both the living body and the calorimeter.

Many substances which will produce heat energy in a calorimeter could not be burned in an animal body. For example, a gram of pure carbon (charcoal) gives 8.08 calories, and a gram of hydrogen would give 34.5 calories; but neither of these could be oxidized at the temperature suitable for protoplasm. This shows the importance of determining whether foods give as much heat in an animal body as in a calorimeter; and this has been tested with a special apparatus as follows: —

169. Calorimeter for Living Animals. — This consists of a small room with walls arranged to prevent heat conduction as far as possible, with coils of metallic pipes arranged so that circulating water will absorb heat from the air in the room, and with machinery for ventilation. Delicate apparatus attached to the pipes for supplying air and water record changes in temperature, and chemical analyses are made of foods, breathed air, and excretions. There is also inside the room a foot-power machine connected with a small dynamo

or otherwise arranged so that the man may treadle the machine and thus do easy, moderate, or hard work for eight hours per day. Thus it is possible to determine the effect of different amounts of work upon food requirements.

Inside such special calorimeters men have lived constantly for several days at a time; and chemists have carefully compared the heat value of the foods oxidized with the heat given off from their bodies to the air of the room and measured by the apparatus.

The results of many such experiments have shown that foods are oxidized as stated in § 168 above. The apparatus has proved of great value in cases where the value of a food to a living animal or to man was unknown.

Many experiments with different combinations of foods have led to the conclusion that men of about 150 pounds weight engaged in sedentary work require food yielding from 2000 to 2400 calories per day of 24 hours. Men doing hard physical work for eight hours per day require food furnishing from 3000 to 4000 calories; and very hard work may require more than 5000 calories. There are individual variations among men of equal weight doing the same work. Some idea of the meaning of these figures will be gained from the statement that 100 grams of protein food giving 400 calories, 100 grams of fat giving 900 calories, and 250 grams of carbohydrates giving 1000 calories make a total of 2300. This would suffice for a sedentary professional man or a shoemaker, but a farmer, mason, or carpenter would require more fat and carbohydrate food daily.

170. Foods for Muscular Work. — It was formerly supposed that protein foods are necessary for muscular work, and we frequently hear that "laborers must eat much meat in order to get strength to work." This is not true. It has been shown that muscular exercise does not require more

protein food, for fats or carbohydrates can furnish the necessary extra energy. Two physiologists who used a mixed diet of proteins and the other foods have proved that their bodies oxidized as much protein on a day of rest as on a day when they climbed a mountain over 6000 feet high; and also that the amount of energy in the protein they oxidized was not sufficient to lift their bodies so high. Hence the other foods (fats and carbohydrates) eaten must have supplied the necessary extra energy. But if these men had eaten more pure protein, they could have gotten from it the necessary energy.

The conclusion from many such experiments is that large amounts of protein are not needed for ordinary work. The necessary amount is approximately the same for every day, whether one is keeping quiet or working, and is from 60 to 100 grams of protein for a 150-pound man. Most well-to-do people eat on the average more than 100 grams of protein in meat daily, and also they get much additional protein in milk, eggs, bread, all vegetables — in fact, there is some in most common foods.*

While the amount of protein foods needed daily is quite constant for the ordinary adult, the amount of the other foods should be in proportion to the energy required. A student certainly needs less fats and carbohydrates than a laborer does. So long as digestion is good, variation in weight is a good index to the quantity of such foods needed; for if they are taken in excess and digested, there will probably be increased weight due to storage in the fat tissues of the body. Loss in weight by an adult who daily eats as much

* Per cent of protein in foods: lean meat 15–22; eggs 15; white bread 9; dried beans 22; potatoes 2; peanuts 25; butter 1; oatmeal 16; olive oil 0; white sugar 0; milk 3; green corn 3; fish 15–20; apples 0.4; rice 8; carrots 1; plums 1.

as 100 grams of protein indicates a need of more fats and carbohydrates; and whether starch, sugar, or fats should be used depends upon availability and digestibility of these foods, and taste of the individual.

Growing animals and children require a higher proportion of protein (see § 172) than do adults, who alone have been considered in the above discussion.

171. Foods for Heat. — As previously stated, birds and mammals must maintain a constant body temperature. To a large extent they do this by preventing excessive loss from the skin. The production of heat is in part the result of muscular activity. We all know how easily we can keep warm by exercise on a cold day, but how uncomfortably cold we often feel if we simply eat our regular meals and keep quiet. For this reason we require more clothing or covering when sleeping, for then the circulatory and respiratory muscles and chemical changes in the digestive organs are the chief sources of heat production.

More food is required in cold weather. The non-nitrogenous foods are most economically increased; but whether fats or carbohydrates should be used for increasing heat depends upon their availability and digestibility. The inhabitants of very cold regions can get fat from animals, while those in temperate regions can store plant food, containing large amounts of carbohydrates, for winter use. When both kinds of foods are available, there is great individual variation in taste for and digestion of carbohydrates and fats; and any desired combination of the two may be made, provided that we remember the energy value of fats as 9 calories, while sugars, starches, and proteins yield 4 calories per gram.

172. Foods for Repair and Growth of Protoplasm. — Attention has several times been directed to the fact that living

substance (protoplasm) is composed of protein. Also, it has been stated that animal cells can make new protoplasm only from protein foods, while plant cells can make protein from the elements furnished by carbohydrates and the nitrogen-containing substances absorbed from the soil. There is abundant evidence that in the human body protein food is required for making new protoplasm in repair and growth; and that the foods lacking nitrogen (*i.e.*, carbohydrates and fats) cannot answer this purpose.

The amount of protein food required daily for repair of the protoplasm in the cells of an adult man is believed to be from 60 to 100 grams (28 grams to an ounce). However, it should be said that some physiologists hold that 100 is nearly twice the amount which is absolutely necessary; but many conservative authorities regard 60 grams of protein as too little for a regular daily diet intended for repair and the maintenance of good health.

If 200 grams of protein be eaten daily, the nitrogen excretion is double that from 100 grams. This indicates (1) that protein is easily disintegrated in the living cells, (2) that excess protein in the food is not stored for possible future use, and (3) that if excess protein goes to cells they use the necessary amount for making new protoplasm and disintegrate into excretions the remainder, which may serve as a source of energy. In other words, at least one-half of the 200 grams of protein might furnish heat or muscular energy as other foods do.

173. Why limit Protein Food? — Since protein is necessary for repair and growth, and may also supply energy, we may properly ask why physiologists so often recommend a limited protein diet, *e.g.*, 60 grams per day. There are several answers: —

(1) Protein as a source of energy is physiologically waste-

ful, for the human body can obtain only about 4 calories per gram, which in the chemist's calorimeter shows 5.6 calories. This is because nitrogen excretion leaves the body incompletely oxidized.

(2) Protein for energy-supply forces the body to handle the useless nitrogen which it contains, for energy comes from oxidation of the carbon and hydrogen. A hard-working man getting about 2880 calories from a daily diet of 120 grams of protein, 100 of fat, and 375 of carbohydrates would have to eat about 720 grams of protein daily to get the same amount of energy if he took no food other than lean meat. This would require the kidneys to excrete 200 extra grams of urea which would come from the nitrogen content of the extra 600 grams of protein. Such an excess of nitrogen excretions is injurious and tends to cause disease of kidneys and other organs. Hence, it is better to get the necessary energy from 100 grams of fats and 375 of carbohydrates ($100 \times 9 + 375 \times 4 = 2400$ calories) rather than from 600 of extra protein ($600 \times 4 = 2400$ calories).

(3) Protein is not economical in a pecuniary sense. It costs much more than common carbohydrates (starch in vegetables, or even sugar) which have the same energy value, namely, 4 calories per gram; and clear lean meat is much more expensive than fat meat or butter when we consider that fat has 9 calories per gram, and hence has more than double the energy value of protein, which has 4 calories per gram.

174. Mixed Diet. — The three reasons given above have led all physiologists to advocate a mixed daily diet containing (1) the protein necessary for daily repair, and for growth in early life; and (2) enough non-nitrogenous foods to furnish the necessary heat and muscular energy. Whether these foods for energy should be fat or carbohydrates depends

upon availability and digestibility. One man may digest and use 100 grams of fat and 300 of starch as well as another could use 50 grams of fat and 412 of starch; but the energy obtained is nearly the same.

Special foods are not known for special organs. That celery is a "nerve" food, fish a "brain" food, lean meat a "muscle" food, etc., are popular beliefs which are entirely without scientific foundation.

It is not yet known whether proteins from plants are equally valuable with those from meat. Certainly many people have lived well on a vegetarian diet; but those who adopt it in its strictest form without milk, cheese, and eggs should eat more than 600 grams of protein, because much of the protein in plant tissue is not easily digested, and moreover it is not known that the human cells use all kinds of plant proteins for use in repair and growth of protoplasm.

It also should be noted that with a strict vegetarian diet there may be difficulty in getting enough protein without an excess of carbohydrates, because there is relatively little protein in many plant tissues. However, certain seeds (especially beans, peas, lentils, wheat, rye, and oats) contain much more protein than the "green vegetables" (roots, stems, and leaves of plants). Hence, it is possible by using such seeds to make a strict vegetarian diet with proper proportions of protein and other food. However, the safest way for most people is to add milk and its products and eggs to plant foods, if one has tastes or principles opposed to the use of a limited quantity of meats. On scientific grounds there is no known objection to the proper use of meats, but simply an objection to meats in excess of actual protein requirements (*i.e.*, above 60 to 100 grams a day).

References: Those who are interested in questions of diet should read the chapters on "Nutrition," and "Hygiene of Feeding" in

Hough and Sedgwick's "Human Mechanism." Also obtain from the Department of Agriculture, at Washington, the bulletins on the nutritive values of foods.

OXYGEN-SUPPLY

175. Respiration. — This has already been defined as including the functions of obtaining oxygen and eliminating carbon dioxide. In some lower animals (*e.g.*, earthworm) the skin is the respiratory organ; in fishes and others there are gills; amphibians breathe with both skin and lungs; but in the vertebrates higher than the amphibians lungs are the sole respiratory organs. In all these cases the membranes which take up oxygen also give out or excrete carbon dioxide. For greater convenience in study, we shall in this lesson confine our attention to the supplying of oxygen to cells in the human body; and deal with the excretion of carbon dioxide in the next lesson.

The respiratory organs consist of nasal passages, pharynx, larynx, trachea (windpipe), bronchi (right and left branches of the trachea), bronchial tubes (branches of bronchi), air-chambers at ends of smallest bronchial tubes, diaphragm, and wall of the thorax or chest-cavity.

176. Respiratory Passages. — We commonly think of the nose as an organ for the sense of smell; but the fact is that only a limited amount of epithelium (lining membrane) in some of the upper nasal cavities has nerve-endings connected with the olfactory or odor-perceiving part of the brain. Most of the cavities in the nose are respiratory, and serve the purpose of warming the in-rushing air by contact with the warm membranes; and also the membranes and hairs in the nose collect much of the dust from the air which enters.

The passages connecting those of the nose with the pharynx are called *post-nasal*. They lie back of the soft palate.

Into the same passages open the Eustachian tubes from the ears. Some of the soft tissues in the lining of the post-nasal chamber may enlarge and form *adenoids* (§ 199), which interfere with free breathing through the nose and cause injurious breathing through the mouth.

177. Structure of Lungs. — (*D* or *L*) Examine sheep's lungs obtained from a meat-market. Notice the *trachea* and the arrangement of its cartilaginous rings, incomplete on the side next to the esophagus. Follow the two branches (*bronchi*) to the lungs. Try inflating the lungs by forcing air through a large glass or wooden tube inserted into the trachea. If it is found that one of the lungs has been punctured, insert the tube into the bronchus of the uninjured lung and inflate. The free lungs can be inflated larger than when they are inclosed in the chest-cavity of the sheep. Now, notice that when you cease blowing and allow air to escape through the tube, the lungs quickly return to their original size. This is caused by the elastic tissue in the lungs. Why does a rubber balloon collapse when the air is free to escape? The answer to this question is the chief reason why air is expired or breathed out of living lungs. How air is inspired or breathed in by living lungs, will be considered in the next section.

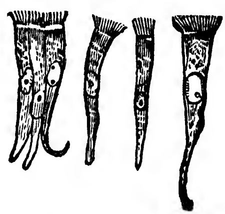

Fig. 64. Ciliated epithelial cells from the trachea of a dog. The hair-like processes on ends of cells project into cavity of the trachea. They have constant lashing movements. (*After Sharpey.*)

The delicate outer membrane of the lungs is the *pleura*, and similar tissue lines the chest-cavity. These membranes are lubricated by a secreted liquid which reduces friction between the lungs and the chest-wall during the movements of respiration. Inflammation of these membranes, which often occurs in connection with severe "colds," is termed *pleurisy*.

Cut into one bronchus and then split it open as you work toward the smaller branches. In this way follow up and lay open a series of successively smaller branches leading out toward the surface of the lung. The smallest branches end in air-chambers. Notice the numerous blood-vessels in the tissues of the lungs. The arteries can be distinguished by walls thicker than those of the veins.

178. Breathing Movements. — Expansion of the chest-cavity results in the external air entering through the trachea into the air-chambers of the lungs.

Action of Diaphragm. — (*D*) Use apparatus constructed as follows: A sheet of dental rubber is stretched and tied over the base of an open-top bell-jar, or lamp-chimney which is wide at base and narrow at top. A short glass tube is tied into the mouth of a delicate rubber bag (*e.g.*, toy-balloon), and the free end of this tube is then inserted through a hole in a cork which will fit tightly into the top of the bell-jar. When the cork is placed, the rubber bag should hang near the center of the jar. The glass jar represents the walls of the chest-cavity, the glass tube represents the trachea, the rubber bag stands for the elastic lungs, and the rubber sheet at the bottom acts as a diaphragm. Note that when this is made convex by pressure, the rubber bag (imitating lungs) collapses. Why? Why is air forced out of the toy-balloon when its tube is open? When the rubber diaphragm becomes flat (imitating the downward or posterior movement of the human diaphragm), the rubber "lungs" expand. Why? Why does water rush into a pump when the piston is raised? This apparatus illustrates the mode of respiratory action; but is not exact, for the lungs fit and fill the chest-cavity, except that the heart lies in a space between them.

The expansion of the human chest-cavity is due to breathing movements, which are of two kinds: (1) those of the diaphragm, whose positions, due to muscular movements, may be imitated by the rubber sheet across the mouth of the jar used in the preceding demonstration; and (2) to expansion of the side-walls, increasing the diameter in a horizontal plane. This latter is due to raising the ribs, and can be demonstrated by measuring with a tape the circumference of the chest before and after inspiration. Young children expand the chest-cavity chiefly by the movements of the diaphragm; in many men the diaphragm does most of the breathing work; in some women, particularly when tight clothing is worn, the diaphragm is but little used, and ex-

pansion of the chest-cavity is due chiefly to movements of the upper ribs. The ideal breathing movements combine to use both ribs and diaphragm.

(*L*) Count the number of breathing movements per minute (about 15 is usual). Do this first while sitting quietly, and later after you have taken rapid exercise for a few minutes. Also, note the movements of the abdomen and of the ribs when breathing deeply and with loose clothing.

179. Changes in Breathed Air. — Analysis of air which has been taken into the lungs and then expired shows that it has lost oxygen. This means that the blood circulating in the capillaries of the lungs has absorbed some oxygen from the air in the air-chambers or air-vesicles around which the blood-capillaries are arranged.

The lungs of the average adult man contain at the close of a normal or quiet inspiration about 230 cubic inches of air; and about 30 of this will be breathed out and exchanged for as much fresh air. It is easy to remember that about one-eighth of the air in the lungs is changed by each breathing movement, *i.e.*, about 15 times per minute when one is breathing quietly. How many cubic feet of air will be breathed in and out in 24 hours?

If a man takes a normal inspiration and then a forced expiration (by "blowing hard"), about 130 of the contained 230 cubic inches of air will be expelled, leaving 100 that cannot be forced out of the lungs. If a man breathes deeply (forced inspiration), he can take in 100 cubic inches more than the 30 of quiet breathing, making 130 taken in and added to the 200 left in the lungs, total 330 cubic inches. This is the full capacity of the human lungs at the greatest possible distension. Of this 330, 230 may be expelled by forced expiration. Obviously, a man trying to make a record on a spirometer, such as are often used in gymnasia,

should first inhale deeply so as to get 330 cubic inches, and then exhale forcibly so as to expel all but 100 that can never be forced out.

The above figures are approximately correct for many adults, but individuals vary greatly in lung capacity.

The advantage of frequent practice in deep breathing, often recommended by physicians, is that the extra 100 cubic inches of air forced in will expand the lungs unusually and thus allow fresh air to penetrate into air-passages which are not properly aired or ventilated by the 30 cubic inches ordinarily inspired.

180. Absorption of Oxygen by Blood in Lungs. — The main blood-supply to the lungs is venous, from the right side of the heart, which in turn receives most of it from all the organs except the lungs, but the bronchial veins return a small amount of blood to the right auricle from the lungs. This venous blood passes through the capillaries of the lungs and goes by way of the pulmonary veins to the left side of the heart, thence to all the organs of the body; but with only a small amount *via* the bronchial arteries to their capillaries in the lungs. On the way through the lungs the venous blood is changed to arterial, by losing part of the carbon dioxide and absorbing oxygen from air in the air-chambers through the delicate walls of the chambers and into adjoining blood-capillaries.

We must guard against the common error of supposing that venous blood coming back to the lungs from all other organs is devoid of oxygen. The fact is that every 100 cc. of venous blood coming to the lungs has about 10 cc. of oxygen dissolved in the blood, and when it leaves as arterial blood it has about 20 cc. In other words, the amount of oxygen is doubled in arterial blood. This additional oxygen becomes combined with the hæmoglobin in the red corpuscles,

and results in the change of color. Blood without the red cells could not contain so much oxygen, and hence vertebrates have a great advantage over the lower animals.

181. Distribution of Oxygen to Cells. — Blood carrying oxygen received in the lungs passes from the left auricle to the left ventricle of the heart and thence to all the organs, even a small amount going back to the lungs in bronchial arteries. As the blood flows through the capillaries in organs, some of its oxygen is absorbed by near-by cells and some by the lymph, which distributes it to cells that are distant from blood-capillaries. Recalling the statement that all living cells are continually using oxygen, it is obvious that they must demand constantly a fresh supply. If the blood were to stop flowing for even a short time, the available oxygen in every organ would soon be used by the oxidation going on in protoplasm; and the result would be asphyxiation of the cells. But under normal conditions the flow of blood is so rapid that only approximately one-half of its contained oxygen is extracted while it flows from the arteries through the capillaries into the veins. Hence, venous blood returning to the lungs has about one-half the oxygen of the arterial blood leaving the lungs (10 per cent in venous, 20 in arterial).

EXCRETION

182. Purpose of Excretion. — The products of oxidation in the cells of the human body are of no further use, and when accumulated may be injurious. Hence special organs have as their work the elimination of excretions (1) from the blood and lymph which absorbs them from the cells, and (2) from the body. Most important of the excretions are, as in the case of all other organisms we have studied, carbon dioxide (CO_2), water (H_2O), and nitrogenous excretions. The carbon dioxide is chiefly excreted by the lungs, the water

by the kidneys and some by the skin, and the nitrogenous excretions chiefly by the kidneys.

183. Excretion of Carbon Dioxide. — Venous blood entering the lungs contains about 46 cc. of carbon dioxide in 100 cc. of blood, and the arterial blood leaving the lungs has only about 40 cc. Thus it appears that approximately one-eighth of the contained carbon dioxide is excreted as blood flows through the capillaries in the lungs.

The chief difference between arterial and venous blood is that the arterial has twice as much oxygen and seven-eighths as much carbon dioxide. The small amount of nitrogen dissolved in the blood is always the same (1 to 2 per cent), for free nitrogen takes no part in the activities of living cells in animals.

It is incorrect to state, as do some old books, that "venous blood is purified in the lungs" and that "arterial blood is pure." The removal of only one-eighth of the carbon dioxide does not make "pure." We should not say that we have made muddy water "pure" if only one-eighth of the mud is extracted. The words "pure" and "purify" should *never* be used in connection with respiration of blood in the lungs. It is easy to remember that blood doubles its oxygen and loses about one-eighth of its carbon dioxide in changing from venous to arterial blood in the lungs.

Carbon Dioxide in Expired Air. — (*D*) Connect a bellows, bicycle-pump, or atomizer bulb to a glass tube, and blow air into some lime-water (or barium-water). Note the effect. If much cloudiness (precipitate) appears, compare with out-of-door air pumped directly into the lime-water.

Now, exhale air from the lungs through a glass tube into lime-water. Compare with the lime-water mixed with fresh air in above experiment.

184. Excretion of Nitrogen and Water. — This work of the kidneys is carried on by the numerous tubules in these

organs. A section of a kidney prepared for microscopic study shows tubules cut transversely, longitudinally, and obliquely; and surrounding the tubules are abundant blood-capillaries. The cells composing each tubule extract nitrogenous excretions and water from the blood, and then eliminate them into the cavity or lumen of the tubule. The water washes the excretion out of the tubule into the *ureter* or kidney-duct, which in all mammals extends from each kidney to the bladder. This is a reservoir for the temporary storage of the excretions (urine) of the kidneys, and in all mammals is connected with the exterior by a duct known as the *urethra*.

185. Skin in Excretion. — Under conditions of high temperature the human skin-glands eliminate water ("sweat" or "perspiration") in which is dissolved salt and small quantities of other substances commonly excreted by the kidneys. However, all the water and other substances could be excreted by the kidneys, and so the skin is not a necessary organ of excretion. It will be explained in § 196 that the skin eliminates water in order to get rid of excess heat, and hence excretion of water is not the primary work of the skin-glands.

SUMMARY

186. Functions Serving the Cells. — (1) Digestion and absorption of foods are functions for getting dissolved foods into the blood, which directly or through the lymph distributes it to the cells of the entire body. (2) The lungs are adapted to supplying the blood with oxygen, which is then distributed to the cells. (3) The excretory organs (chiefly lungs and kidneys) are adapted to remove from the blood the various excretions formed in the cells. (4) The circulating liquids (blood and lymph) serve the functions of food-supply,

oxygen-supply, and excretion, in that food and oxygen must be distributed to the cells and excretions taken away to the excretory organs.

These four great functions, involving the organs of digestion, respiration, excretion, and circulation, serve the cells. We have noted that a one-celled organism, like an amœba or a paramecium, does not need such a complicated mechanism, for with respect to food, oxygen, and excretions it can deal directly with the external world. The vast number of cells in a higher animal has made necessary the complicated organs of digestion, respiration, excretion, and circulation for serving the cells.

NERVOUS ACTIVITY

187. Need of Coördination. — The functions which serve the cells named in the preceding paragraph must work together or in harmony. For instance, if muscles are working faster, there is need of more food and oxygen. This requires more rapid circulation, greater oxygen-supply, and increased digestion in order to supply and transport the necessary food and oxygen. And faster work results in more excretions and consequently greater activity of the circulatory and excretory organs in removing them. Thus, increased activity of certain organs demands a corresponding increase in the work of many others; and there must be *coördinated activity.*

The function of coördination is part of the work of the nervous system. This is parallel with the case of a frog's functions; but in addition the human nervous system has a vast amount of other work arising from mental activities.

188. Reflex Action. — How the nervous system exerts its coördinating power on other organs may be clearer after a brief account of some simple cases of control.

If by accident one touches a finger to a hot stove, a sudden

contraction of the muscles will cause the hand to be jerked away before the brain becomes conscious of the burn. The explanation of such an action is that the hot stove stimulated sensory *nerve-endings* in the finger, the stimulus was transmitted to nerve-cells in the spinal cord between the shoulders, and at once turned back as a motor impulse, which, transmitted along other nerve-fibers back to the finger, caused the muscles to contract. Since the impulse originating in the stimulated sensory nerve-endings appears to be reflected back to the muscles by the spinal cord, the process is called *reflex action.*

Headless frogs and other animals will make the same reflex movements if their toes are stimulated. This proves that reflex action is quite independent of consciousness (knowing, feeling), for all observations on injured men and animals indicate that the brain is the organ of consciousness. For example, a man with the spinal cord seriously injured, say in the middle of the back, would feel no pain in the legs and could not move them voluntarily; that is, by conscious action from the brain. Such facts, of which many have been recorded in medical books, prove that there must be uninjured nerve-fibers connected with the brain in order to have conscious control of organs. Hence, a headless animal or one with the spinal cord cut off just back of the head could not feel or be conscious of changes occurring in the body.

In the case of instantly closing an eyelid to escape a threatened injury, the stimulation of the nerve of sight (optic nerve) causes a reflex to muscles which move the eyelids.

The above are simple examples of unconscious reflex actions which are constantly occurring. We learn to do a large number of things reflexly, in addition to the fundamental processes such as breathing, heart-beat, digestion,

etc., which naturally and necessarily are subject to reflex control. In walking, playing musical instruments, using various tools, etc., we learn by long practice to act more or less reflexly or automatically, and with little or no exercise of the will (conscious control).

189. Conscious or Voluntary Action. — The instance of touching a hot stove, used above as an illustration of reflex action, also affords an example of conscious action. Soon after the hand is jerked away by reflex action, one becomes conscious of being burned. Obviously, there are nerve-fibers for transmitting the sensory impulse from the tip of the burned finger to the brain. There a conscious action may occur, and it may be reasoned that it is dangerous to keep the hand anywhere near a hot stove, and so on, with the result that it is decided or willed to take the hand far away. This is accomplished by a conscious motor impulse from the brain to the muscles of the arm, causing them to move as the will dictates.

Moreover, the brain may also control the direction of the movement; that is, it may coördinate the contraction of the various muscles. A splendid example of such coördinated voluntary or conscious control of muscles is that of baseball pitchers who can will to throw a ball to a given place and at the same time consciously control the contraction of the muscles of the arm so that the ball will be given the twirling or curving motion so much desired by experts in ball-playing. Learning to do this by long practice means training the nerve-cells in the brain so that they will come to control the muscular contractions and so cause the desired muscular movements.

190. Spinal Cord and its Nerves. — The human spinal cord is usually described as lying in a cavity in the backbone (*vertebral column*). Examination of some of the segments of any backbone which may be obtained at a meat-market will

show that the cord lies dorsal to the central axis. Moreover, the cord is not completely covered by bone, and at the uncovered places are the *spinal nerves*. These are arranged in pairs (thirty-one pairs all together). Each nerve is divided near the cord, and one branch of *root* joins the dorsal side of the cord, while the other joins the ventral side. On each dorsal root is a thickening called *spinal ganglion*, which contains nerve-cells whose fibers extend into the cord and also out through the nerves (Fig. 67). The cells whose fibers constitute the ventral root lie inside the cord.

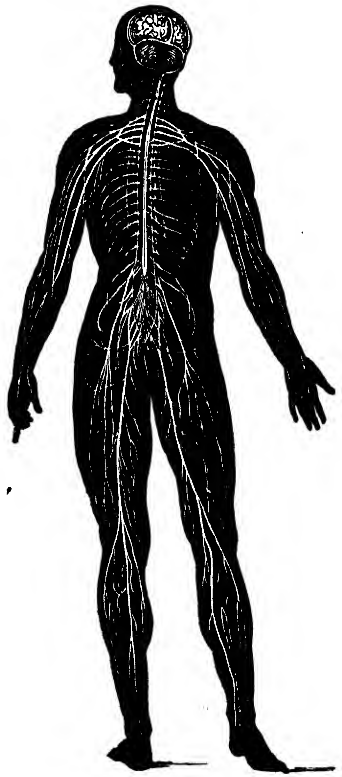

FIG. 65. The white lines indicate the general distribution of nerves from the brain and spinal cord to all parts of the body.

A cross section of a spinal cord shows an X- or H-shaped figure in the center. In a fresh cord this is silvery gray, and is called the *gray matter* (Fig. 67). The surrounding whitish tissue (*white matter*) is chiefly composed of connective tissue and covered nerve-fibers. Many of these fibers extend to the brain and others to the regions of the cord where other spinal nerves are attached. The gray matter contains many nerve-cells, especially those

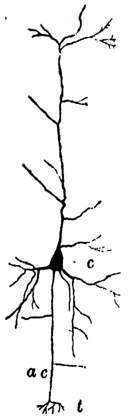

FIG. 66. A nerve cell from the brain. *ac*, axis cylinder; *c*, cell; *t*, terminal fibers.

whose fibers extend out through the ventral root into the spinal nerve and thence to muscles and other organs.

The spinal cord is surrounded by membranes which separate it from the hard walls of the backbone. These contain numerous blood-vessels, some of which extend into the cord. Similar membranes are between the brain and the skull.

Deep furrows or fissures extend longitudinally on both the dorsal and ventral sides of the cord and partially divide it into right and left halves. The membranes which surround the cord extend into these fissures and supply the inner parts of the cord with blood-vessels.

It is known that the *sensory* nerve-fibers (*e.g.*, those of touch in the skin) are connected with the dorsal root of the spinal nerves, and that the fibers which carry *motor* impulses from the cord to the muscles and other organs are in the ventral root. Since the dorsal and ventral roots unite into a spinal nerve, it is clear that each nerve is a bundle of both motor and sensory fibers, each one connected with a nerve-cell in a spinal ganglion or in the spinal cord.

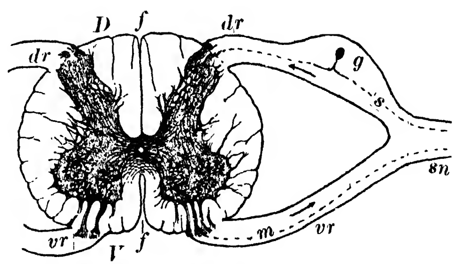

FIG. 67. Diagram of a cross section of spinal cord. X-shaped gray matter in center. *D*, dorsal; *V*, ventral; *dr*, dorsal root; *vr*, ventral root of nerve; *f*, fissures; *g*, spinal ganglion; *m*, motor fibers; *s*, sensory fibers; *sn*, spinal nerve. Dotted lines show paths of fibers from cells.

In reflex action (§ 188) the sensory impulse travels from the skin to the cord by way of the dorsal root, and then in the gray matter is " reflected " to the motor cells whose fibers leave the cord in the ventral root and extend out to the muscles. How this " reflecting " is done is unknown; we only know that events occur as stated. As a parallel case, we know that electricity will " travel " in certain substances according to definite laws; but scientists are very much in the dark as to how and why it does so.

191. The Brain. — The human brain is a very complicated mass of nerve-cells, fibers, blood-vessels, and connective tissue. The following brief account includes the most important facts regarding structure of the brain.

The convoluted mass of the brain in the upper part of the skull is the *cerebrum*, which is divided by a deep furrow into right and left *cerebral hemispheres*. Beneath the back part of the skull and just above the neck lies the next largest part of the brain, the *cerebellum*. Beneath the cerebrum are various small structures, such as the two *olfactory lobes* from which nerves extend to the nose, two *optic lobes* with a nerve to each eye, masses of white tissue through which nerve-fibers connect opposite sides of the brain, several pairs of nerves, and the *spinal bulb* or expanded connection of the spinal cord with the brain. Most of these structures can be identified on a sheep's brain, obtained from a meat-market, and hardened in strong alcohol or formalin solution.

Microscopic study of sections shows that most of the nerve-cells of the brain are near the surface (*cortex*), while inside are the fibers connecting with the spinal cord and also connecting various parts of the brain. Hence a cut across a fresh brain shows *gray matter* (with nerve-cells) on the outside and *white matter* (nerve-fibers) inside, just the reverse of the spinal cord.

The cerebral hemispheres are the center of mental life, consciousness, and voluntary action. The cerebellum is the center of coördination, causing muscles to work in definite and controlled ways. The nerve-cells which control the respiratory movements and the circulatory organs are in the spinal bulb.

Localized centers in the cerebrum are known to exist. So far our knowledge is limited, but there are areas in the surface layers where the nerve-cells are concerned with special organs; for example, there are such centers for muscular movements concerned in speech, for hearing, taste, and smell, sight, touch, and voluntary movements of various organs. This discovery of localized centers in the cerebrum is already valuable to surgeons. For instance, if an injury to a brain interferes with any of the functions named above, the surgeon knows approximately where to look for broken blood-vessels and other injuries.

The discovery of the centers controlling certain functions has no bearing upon the once-popular pseudo-science called phrenology, which pretended to locate certain general mental powers by the contour of the skull. It was utterly unscientific because (1) there is no evidence of such localization as phrenology claimed, and (2) there is much evidence against the idea that the outer surface of the skull indicates the degree of development of the brain beneath.

ORGANS OF SPECIAL SENSES

192. Structure of Eye. — Use a hand-mirror and examine your own eyes after reading the next two paragraphs. Refer frequently to Fig. 68.

The center of the outer coat of the *eyeball* in front is the transparent *cornea*, through which one can look into the in-

terior of the eye. All the remainder of the outer coat of the *eyeball* is hard, white, and opaque (the sclerotic coat). One might imitate the external appearance of an eyeball by painting a glass ball white, excepting a circular spot to represent the transparent cornea.

Inside the cornea, and of nearly the same size, is the black, gray, or blue part of the eye with a hole in the center. The color pigment is in a sort of thin membrane (called *iris*), and the hole in the membrane is the *pupil*. Just back of the pupil is the *lens*, which is bi-convex, transparent, and elastic, so that by pressure its shape can be changed. Back of the lens is the sensitive membrane (*retina*), which is closely attached to the back wall of the eyeball and hence is hemispherical in shape. From near the center of the retina the *optic nerve* extends to the brain.

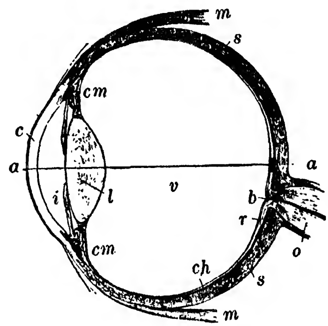

FIG. 68. Diagram of eye. *a*, axis; *b*, blind spot; *c*, cornea; *ch*, choroid; *cm*, accommodating muscle; *i*, iris; *l*, lens, *m*, directive muscles; *o*, optic nerve; *r*, retina; *s*, sclerotic coat; *v*, vitreous humor.

The space between the lens and the retina is filled with a transparent jelly-like substance (*vitreous humor*). The small space between the lens and the cornea is filled with a watery fluid (*aqueous humor*). If an *eyeball*, obtained from a meat-market, be punctured, these humors escape and the eyeball collapses. They are so transparent as not to interfere with the passage of light from the cornea to the retina.

Between the retina and the outer white coat (sclerotic) is a layer of tissue (*choroid*) with abundant blood-vessels and black pigment. The pigment in the choroid and iris pre-

vents light from entering the eye except through the pupil and the lens. In the same way black pigment in a photographic camera prevents light from reaching the sensitive plate or film except through the lens and the opening of the diaphragm which corresponds in use to the iris and its opening.

In both a camera and an eye the whole structure is essentially a light-proof box with a diaphragm or iris for regulating the amount of light, and a lens for focusing the rays of light upon a sensitive plate or retina. The chief differences between a camera and an eye are: (1) the eye is living tissue; (2) the sensitive plate or retina of the eye contains living nerve-cells connected to the brain by nerve-fibers of the eye-nerve or *optic nerve;* and (3) the lens of the eye is focused, not as in a camera by moving the sensitive plate nearer to or farther from the lens, but by muscles which change the shape of the eye-lens. (4) There is always the same "plate" (*i.e.*, retina) in the eye.

The adjustment of the lens to suit different distances of objects seen is called *accommodation.* It is accomplished as follows: The lens when not compressed is very bi-convex, as may be seen in a lens cut from an eye obtained at a meat-market. When an eye is resting in sleep or is looking at far-away objects, the lens is much flattened (or made less convex) by the pull of the elastic choroid upon the transparent capsule which incloses the lens and attaches it to the choroid. In order to see clearly near-by objects the lens must be focused by being made more convex. This is simply the elastic return of the lens toward its natural bi-convex shape, and this return is permitted by a sheet-like circular muscle which opposes the elastic pull of the choroid and thereby eases the tension upon the lens.

It is evident from the above that the feeling of strain when we look at very small objects is due to the pull of

muscles against the constant elastic pull of the choroid upon the capsule that incloses the lens.

(*D*) In order to study the effect of change of shape of the lens upon the focus of the eye, first set up a photographic camera and focus upon near and distant objects by moving the lens. If one had lenses for different distances (very bi-convex for near-by, and less so for far-away) the distance from the lens to the sensitive plate might be kept stationary in a camera. In the case of an eye the distance to objects seen varies, and there is need of many lenses of different curvatures; or better still, of one elastic lens whose shape can be changed to fit objects at any distance.

Eyes that cannot see distant objects clearly are said to be "near-sighted," and one with such eyes must hold print very near in order to bring it into focus. This is due to the lens being abnormally distant from the retina. Concave glasses should be worn in order to change the direction of rays of light and cause them to focus on the retina. Other eyes are "far-sighted," and only by constant strain can the lens be kept convex enough to focus the rays on the retina, which is abnormally near the lens. Even when straining to the utmost, some persons must hold books at arm's length in order to read. Convex glasses correct such difficulty and relieve the excessive strain. In old age the lens loses some of its elasticity and fails to become convex enough when trying to read, and hence a book must be held at a distance, unless convex glasses are used. Astigmatism is a very common congenital or inborn defect due to irregular curvature of the cornea or lens, making it impossible to see equally well lines which run in different directions, as on a clock-face. For such eyes so-called "cylindrical" glasses should be used constantly to avoid eye-strain.

193. The Ear. — The human organ popularly known by this name is the *external ear*, from which a tube leads inward

to the *tympanic membrane,* or ear-drum. Beyond this is a cavity known as the *middle ear,* and from it the *Eustachian tube* leads to the pharynx. Still deeper in the head is the *inner ear,* a complicated membranous structure lying in bony cavities of corresponding shape. The lower part (*cochlea*) is shaped like the cavity in a snail's shell and the upper part has three ring-like canals (*semi-circular canals*). Branches of the *auditory nerve* connect the sensitive membranes of the inner ear with the brain.

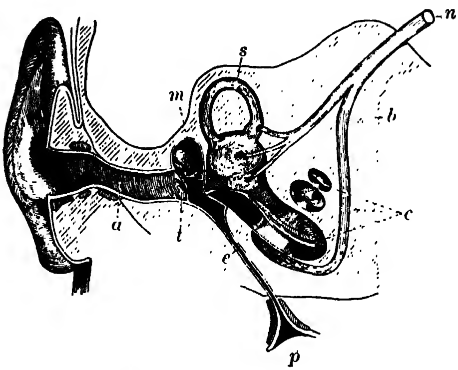

FIG. 69. Diagram of human ear. *a*, canal from external ear; *t*, tympanum; *m*, middle ear with small bones extending from tympanum to inner ear; *s*, one of the semi-circular canals of inner ear; *c*, cochlea of inner ear; *n*, auditory nerve; *b*, bone surrounding middle and inner ears; *e*, Eustachian tube, and *p*, its opening to pharynx.

The inner ear is filled with a fluid. Sound vibrations enter the outer tube, and throw the tympanic membrane into vibration. This moves a *chain of three bones* which extends across the cavity of the middle ear to the membranous wall of the inner ear. Through this membrane vibrations are passed on to the fluid of the inner ear, and its vibrations stimulate the sensory endings of the auditory nerve which are sensitive to sound. The semi-circular canals give us the *sense of equilibrium,* of which we are aware even when we are blindfolded.

194. Smell, Taste, Touch, Temperature. — These senses are connected with special nerves. Those of smell have

endings in the epithelium which lines certain upper cavities of the nose. The nerves of taste end in the little projections (*papillæ*) on the tongue. Those of touch and temperature are widely distributed in the skin of all parts of the body.

THE SKIN AND ITS WORK

195. Human Skin. — Microscopic preparations show that the surface of the skin is made up of closely set cells, while the lower side next to the muscles and bones is made up of connective tissue (Fig. 70). The cellular layer is the *epidermis*, and the connective tissue is the *dermis*.

(*D*) A piece of leather tanned without the hair will give a good view of the intricately interlaced fibers of the dermis, the epidermis having been removed in the process of tanning. Soften such a piece of leather by soaking in hot water, and then examine by tearing it apart.

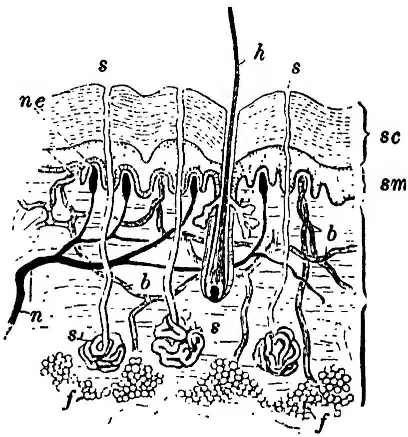

FIG. 70. Diagram of section of skin. *b*, blood-vessels; *d*, dermis; *f*, fat; *h*, hair; *n*, nerves; *ne*, nerve-ending; *s*, sweat-glands and their ducts; *sc*, horny layer of epidermis; *sm*, living layer of epidermis. (*After Wiedersheim.*)

(*L*) The dermis is tied down to deeper tissues by *connective-tissue fibers*, many of them elastic. Pull up the skin on the back of your hand, and note how quickly it returns to place when released.

With a hand-lens examine the skin on arm or hand. Note the delicate ridges and grooves, especially on the finger-tips. Press

the finger-tips on an ink-pad and then make prints on paper. No two persons have the same *finger-prints;* and so this has proved to be a valuable means of identification, especially in records of criminals.

The surface of the skin looks scaly as seen under a strong lens. These *scales* are dried *cells.* They swell in solutions of caustic-potash or washing soda, and pieces scraped from a calloused spot on the palm may be so treated in preparing for microscopic examination. This swelling when wet explains why the hands get so soft when kept for a time in water, especially soapy water.

A microscopic section shows that the scaly cells at the surface are many layers thick, and that deeper down in the epidermis are several rows of rounded or cubical cells, which are usually brightly stained in preparations. These are living cells, while the hard scaly ones at the surface are dead. The scaly cells together constitute the *horny layer,* and the lower cells of the epidermis form the *Malpighian layer,* or living layer. The horny dead cells at the surface are continually wearing off, and the deeper living cells are by division forming new cells, which are pushed toward the surface.

In warts, corns, and callouses the horny layer becomes greatly thickened. The lower living cells form new cells faster than the hard cells at the surface wear off. Friction, pressure, and introduction of some foreign substance through a cut or scratch are some of the well-known causes of these thickenings of epidermis.

In the ordinary healing of a cut or burn, the cells of the living layer form new cells to fill the gap beneath the blood-clot or "scab" which forms on the surface. In extensive burns it is sometimes necessary to resort to *skin-grafting.* This means taking healthy pieces of skin from other persons and applying them where the epidermis has been completely

destroyed. The cells of these healthy bits of grafted skin soon become firmly attached and by repeated division grow over the injured surface.

Nails and hairs are specialized masses of horny cells. The so-called " roots " of nails and hairs are deep-lying masses of living cells which grow and divide rapidly. The pit in which each hair is attached is called a *hair-follicle*, and in it is a conical elevation (*papilla*) from which the hair grows as cells are formed and pushed outward. *Oil glands* (sebaceous glands) open into the hair-follicles. Cutting or shaving hair, contrary to popular belief, does not increase the number of hairs, for the follicles are formed in embryonic life.

(*L*) Examine a hair with a microscope, and note that it is composed of overlapping scales (cells). The center is also filled with cells. The idea of barbers that hairs are hollow and require singeing to prevent the escape of oil is absurd — but profitable to the barber.

Sweat-glands are abundant over the whole human skin. They are most numerous on palms and soles, which also have no hairs. Each sweat-gland is a tube extending from the so-called " pore " down into the dermis, where it is much coiled and surrounded by blood-capillaries.

196. Functions of the Skin. — Next to protection, the most important function of the human skin is heat regulation.

While the soft skin of frogs and other lower animals is important for respiration, the dry hard skin of mammals and of man is of little use in this way. It has been shown by putting a man in a rubber bag tightly fitted around the neck that the lungs give off nearly two hundred times more carbon dioxide than does the skin. Hence, skin respiration is of no practical importance to us.

Absorption by the skin is of little importance. Oily materials are often rubbed into the skin, and small quantities

appear to be absorbed. Probably the massage effect is most important. It is known that some drugs can be absorbed when thus rubbed into the skin.

Secretion of Sweat. — Under ordinary temperature conditions the amount of secretion is not noticeable, because it is evaporated as rapidly as formed. Drinking large quantities of water raises the blood-pressure, and increases perspiration. Certain drugs bring about dilation of blood-vessels and cause profuse sweating; others act in an opposite manner.

Normal sweat is nearly 99 per cent water. The one per cent of dissolved material is chiefly mineral excretions similar to those in the urine. If the skin were varnished, the same excretion would be easily eliminated by the kidneys. Sweat, then, is not necessary as an excretion, but as an aid to heat regulation (see next section).

197. Skin as Heat-Regulator. — The fact that the noticeable activities of the sweat-glands are usually associated with great internal heat suggests that the chief function of these glands is not so much to get rid of sweat (which the kidneys could manage) as to discharge heat.

The muscular system is the chief source of increased heat production, while the other organs probably generate the heat which is more or less constant, as during sleep or complete rest. When these organs are unable to supply the necessary heat, shivering, which is involuntary activity of muscles, may begin and thus increase the internal supply of heat.

Some heat is given off in respiration. This is very important for dogs, which perspire little except on the pads of the feet. They " pant " when overheated, and lose heat rapidly from the lining of the mouth and the surface of the protruded tongue. Chickens are often seen breathing rapidly with their mouths open; and thus birds lose heat from their

lungs and air-sacs. In man, however, the skin is the great heat-regulator.

The loss of heat from the human skin is controlled by nerves, some of which regulate the flow of blood to the skin and sweat-glands, and some stimulate these glands to activity. Rapid exercise causes the sweat-glands to become active. The effect of the sweat is illustrated by the familiar cooling of bottles of water wrapped with wet towels exposed to warm air; of water allowed to evaporate from the hands or face on a summer's day; or of the porous water-jugs and canvas bags which the inhabitants of some hot countries use for their drinking water because the small amount of oozing water is evaporated and cools the water in the jug. We know also that following a bath on a hot day the body cools rapidly, and the explanation is that the heat of the skin was used to evaporate the water. Now, the sweat-glands are simply mechanisms for covering the skin with water ready for evaporation at all times when the skin is warmed by overheated blood.

In addition to the heat lost by evaporation of water on the surface, there is much loss by radiation, especially in cold weather when the skin gets warm after exercise. Certainly at such times the warmer skin must radiate more heat to the air, just as does a hot-water pipe when the temperature of the circulating water increases.

The importance of sweat evaporation as a method of cooling the body depends upon the temperature and humidity of the surrounding air. Dry cold air takes up very little watery vapor, while dry warm air takes up much water. Hence in hot weather loss of heat by the evaporation of sweat becomes more important. Obviously, hot dry winds would favor evaporation; while hot moisture-laden air prevents rapid heat loss both by radiation and by evaporation.

This is the usual condition on oppressively hot days when heat prostrations and sunstrokes are common. The moist hot air prevents proper loss of heat from the skin, and the internal temperature rises too far above 99° F., which is the best temperature for human protoplasm. Obviously, reduced heat production will help to prevent excessive internal heat; and this means keeping as quiet as possible and eating sparingly, in order to reduce the activity of muscles and the digestive organs. (Why do people in tropical climates with hot sun and moisture-laden winds suffer from heat more than do the inhabitants of equally hot but dry regions?)

Fever is due to increased production of heat (caused by toxins of disease), and is usually accompanied with dry skin and inactive sweat-glands; but occasionally even great perspiration does not discharge the heat fast enough. The so-called "wasting" indicated by loss of weight during prolonged fever is due to the rapid oxidation of tissues when little or no food is available. Drugs affect fevers by reducing oxidation in tissues or by promoting perspiration and consequent heat loss from the skin.

The effect of cold baths upon heat regulation by the skin is considered in § 208.

CHAPTER IX

BIOLOGY APPLIED TO PERSONAL HYGIENE

198. Hygiene. — In this chapter it will be shown that very many of the facts and principles of biology are of great value when applied to making the human body freer from disease and a more efficient mechanism for carrying on a useful and happy life.

That department of biological science which deals with the established principles of human health is commonly known as *hygiene*. It is simply a phase of applied biology. Whenever hygiene deals with the health of individuals, how to take care of oneself, as in rules for eating, breathing, sleeping, etc., it is called *personal hygiene*. This is chiefly the principles of biology, particularly of physiology, applied with a good proportion of common sense. By this we mean, for example, that one who has studied the structure and working of the lungs will need only common sense to enable him to see that tight clothing will interfere with the natural movements, and then the hygienic rule "do not wear tight clothing" is seen to be a scientific application of the biological principles relating to human breathing. The same is true with regard to every organ; and we do well to examine every proposed new rule of hygiene from the standpoint of applied biology. Thousands of foolish rules of hygiene have been published, but it is usually possible to select the good ones because they are obviously based upon the principles of biology.

We should keep a sharp lookout for such applications of

biology to the unscientific rules of personal hygiene which so many people accept without question.

Public hygiene or *sanitation* means principles of biology applied to increasing the health of a community of people. Problems relating to clean streets, pure food-supply, infectious diseases, sewerage, and water-supply are aspects of public hygiene with which health officers are concerned.

RESPIRATORY ORGANS

199. Habits of Breathing. — The effect of tight clothing is referred to in the preceding section. All authorities in medicine and hygiene unite in condemning the fashion of wearing any clothing which interferes with breathing movements.

Exercise in deep breathing is important, for it trains the respiratory muscles so that fuller expansion of the lungs occurs regularly. This means that fresh air goes deeper into the air-tubes. Consult your physical-training teacher as to the advantage of training in breathing for athletics.

Breathing through the nose is the natural way, because the air is properly warmed and much dust is stopped in the nasal passages. Mouth-breathing is abnormal, but very common. Children who breathe habitually through the mouth probably have enlarged adenoids in the upper part of the pharynx back of the soft palate. If not removed at once by a competent surgeon, they may seriously interfere with the health, cause deafness, or even deformation of the upper jaw. They commonly disappear after childhood, but then the damage has been done. Hence any special difficulty with natural breathing through the nose should be referred at once to a doctor for advice.

200. Ventilation. — Frequent renewal of the air of buildings is required because the breathing of human beings and

the combustion in stoves, lamps, etc., use oxygen and add carbon dioxide, and because bacteria are carried in the dust of the air. Moreover, human breathing adds moisture and raises the temperature; and this is chiefly the cause of the discomfort one feels in crowded churches and theaters. Electric fans simply keep the air moving inside an overheated room and do not ventilate. All systems of ventilation should provide for the exit of the lighter warm air near the ceiling and the entrance of fresh air (preferably warmed previously by heaters) near the floor. At night when the body is properly protected in bed, the supply of fresh air may safely be very cold. The important rule is to get as much fresh air as possible without chilling any part of the body by drafts. That is far more harmful than poor ventilation, for in this way "colds" are often produced (§ 203). In order to have good ventilation it is not necessary that there should be a noticeable current of air in a room.

For accounts of the best methods of ventilation, see books of hygiene and household science. The subject is so extensive that only the great principles can be suggested here.

201. Avoiding Dust. — Owing to the fact that dust often carries dangerous bacteria and that there is a harmful effect of accumulated dust in the lungs, dust in the air should be eliminated as far as possible from homes, factories, and public buildings. Old-fashioned sweeping and dusting are dangerous unless windows are opened and the wind allowed to blow out the dust and bacteria. Carpet-sweepers and especially vacuum-cleaners are better. Damp cloths should be used for wiping dust from furniture; brushes and feather-dusters are relics of the dark ages and should never be used. If brooms must be used indoors, damp sawdust will help keep dust from rising into the air. The most sanitary modern dwellings have no carpets which are not easily taken outdoors

for cleaning; and the floors are painted, varnished, or waxed so as to make washing easy and sweeping unnecessary.

202. Artificial Breathing. — This means causing the lungs to respire after normal breathing has been stopped by drowning or by gas asphyxiation. One of the best methods of artificial respiration is as follows: The subject is laid on the ground in the prone position with a thick folded garment under his chest. The operator kneels beside the subject (or athwart him), facing the head, and places his hands on each side over the lower ribs. Then the operator slowly throws the weight of his body forward and downward, and thus presses upon the thorax of the subject, which forces air out of the lungs. Then the operator gradually relaxes his pressure, but without removing his hands. These movements are repeated *regularly* at the rate of twelve to fifteen times a minute until normal respiration begins, or until all hope of normal respiration is given up. Many have been restored to life after such movements have been continued for more than an hour. For other methods, see special chapters on "accidents" in books on hygiene. The teacher should give practical lessons on this important topic, selecting one student as patient and another as operator.

203. Colds in Respiratory Organs. — Severe "colds" which are liable to lead to bronchitis (inflammation of bronchial tubes), pleurisy (inflammation of pleura of lungs), or pneumonia (congestion of blood, with certain poisonous bacteria in the lungs) require medical advice. Chronic congestion of nasal membranes leading to the condition known as catarrh should receive medical attention, for a slight operation or special treatment may be necessary to effect a cure.

For preventing colds see § 208 on bathing. One whose skin has been chilled should hasten to restore the normal circulation of the skin by exercise, friction, hot drinks, hot bath

(with great precaution against more chilling), and in extreme cases by certain drugs which physicians advise. It is dangerous to neglect a "cold," especially in its incipient stages.

DIGESTIVE ORGANS

204. Teeth. — The proper care of the teeth is commonly emphasized in the books on "physiology" written for elementary schools, and need not be repeated here. The fact that bacteria are largely responsible for dental decay suggests the daily use of antiseptic tooth-powders and mouth-washes.

205. Hygiene of Eating. — The practicable hygiene of digestion for most people is that which suggests the time for eating, and the amount and kind of food.

The question of the *time of meals* depends upon other physiological demands. A light breakfast and a light lunch are best for busy people whose muscles or nerves are hard-worked. The best time for dinner, the chief meal of the day, is after the day's work and a brief rest. The reason for this is that intellectual activity leads to a marked increase in the amount of blood in the vessels of the brain, and physical work affects muscles similarly. The result must be a withdrawal of blood from the vessels of the digestive organs and a consequent retardation of the digestive process.

The above plan suits most people; but there are numerous individual exceptions, and each one must experiment with himself if he would find the most satisfactory times for meals. Work and habits of human beings vary so greatly that there can be *no universal law of eating.* Certain rules for general application have been established by the experience of thousands of people, and probably most important for remembering are the following: (1) There should be regularity in meals. (2) Physical and mental fatigue interfere with digestion. (3) Overeating acts in a similar way.

The *selection of diet* and its amount is similarly variable. Hard physical exertion and exposure to cold demand abundant food for energy, and the question of easy digestibility is of minor importance. On the other hand, persons of sedentary habits should avoid unnecessary amounts of all kinds of foods; and also observe well their own peculiarities as to digestibility of carbohydrates and fats.

Eating anything *between meals* is, as a rule, inadvisable; but here again there are individual exceptions, and knowledge of the possible harm to digestion will lead to caution.

Some *water* (*not iced*) should be taken at every meal, for it is needed in liquefying the contents of the stomach in preparation for escape into the intestine. But water should not be taken at the same moment with solid food, for it "washes down" the food and thus prevents mastication. The old idea that water dilutes the gastric juice does not now seem to be very significant, for it has been discovered recently that water soon passes from the stomach into the intestine and gastric juice is secreted rapidly.

Overeating is the chief point on which many people need physiological advice. Scientific studies have often shown that men need no more food than stated in § 166, and yet a large number of people take more daily. Especially is it true that we use too much protein (§ 173), thus unnecessarily overworking all organs without any gain. The other foods are also used to excess by many whose daily activities do not require so much stored energy; and the common result is fat-storage, which often becomes so excessive as to be uncomfortable or even a danger to the heart and other organs. In the majority of cases, excessive fat-storage is due to the overeating of foods containing carbon, hydrogen, and oxygen (sugar, starch, butter, and fat meat). The over-fat condition, once established, is difficult to change; and hence young

people should guard against an excessive increase in stored fat due to intemperate eating.

An *excess of meat diet* is more harmful than an excess of other foods, for the reason that most proteins eaten are quickly oxidized and excreted within a day. The nitrogen excretions formed from excess proteins may play an important part in the development of gouty and rheumatic conditions.

The *value of mastication* has been the subject of much discussion, and is still uncertain; for there are some people who masticate little and have perfectly healthy digestion, and there are others who masticate extensively and claim to have thereby cured indigestion. The truth is that it is largely a question of the kind and amount of food and the habits of the individual. Certainly one who eats an excessive amount of starchy food, or who has starch-indigestion in the intestine, will do well to masticate starchy food and allow the saliva to exert its digestive influences as long as possible, for thereby he may cure a form of indigestion. But this does not prove a rule for all people or for all articles of diet; and with no more than the necessary amount of properly cooked food the average individual can safely follow his natural instincts as to the amount of mastication. There are those who point to the rumination of cows and sheep for evidence that naturally animals masticate food for a long time; but this gives no rule for human guidance. In the first place, a cow's natural food is uncooked and otherwise unprepared; second, her digestive organs are quite unlike the human; and third, dogs more closely resemble man in structure and in foods and they never masticate. Obviously, it cannot be concluded that man should chew his food long because cows and sheep do. The only scientific conclusion must be based upon individual human experience; and this indicates that some people with weak digestion of starch need to give

special attention to mastication, but that most people may safely forget their jaws while eating (*i.e.*, masticate instinctively) *provided* that they do not eat too rapidly or in excess. However, it is well for each person to experiment upon himself, and thus determine how far special attention to mastication is important for himself.

One point in favor of thorough mastication deserves mention, namely, that it *tends to prevent overeating.* When food is rapidly swallowed, there may be an excess taken before the gastric nerves give us warning of too much food. Prolonged mastication tends to avoid this result, possibly because the sugar obtained from the salivary digestion acts upon the gastric nerves just as sweets before a meal "take away the appetite" or reduce it. In this way prolonged mastication helps one apply the rule that eating should stop before hunger is completely satisfied.

Stimulants. — Should digestive stimulants be avoided, is a much-discussed question, usually with regard to alcoholic drinks. It also should apply to spices, condiments, coffee, tea, cocoa, carbonated water, and even hot food; for these all have some stimulating effect upon the digestive organs. It is often said that such stimulants are not natural, for animals do not require them; but it may be answered that animals do not lead sedentary lives, undergo intense nervous strain, or otherwise interfere with proper digestion. Certainly we can often gain by the temperate use of some stimulants; but harm will always come from overstimulation, which is most likely to happen in the use of tea and coffee (§ 230) and alcohol (§ 218). Probably the most useful and safest of all stimulants are hot foods and hot drinks, such as hot bouillon, hot milk, or even hot water.

206. Psychology of Digestion. — We have already defined psychology as the science of the mind; and here it is impor-

tant to note that the mind greatly influences digestion. It is well known that the thought, sight, or smell of savory food causes the "mouth to water," that is, stimulates the salivary glands; and there is a similar effect on the gastric glands. We know also how certain disagreeable mental states may cause loss of appetite and even nausea. In fact, the gastric glands may fail to secrete, and indigestion and other disturbances may be caused by the direct influence of the mind.

Such well-known facts suggest the importance of pleasant surroundings while one is eating. Here is the secret of the good digestive influence of music, jolly company, and other things which make for a happy state of mind during the meal hour. That is a time when every one should drop his cares and troubles.

On the other hand, there is a certain real danger in pleasant accompaniments of meals. It is simply that fine fare and surroundings which are agreeable to all the senses tend to feasting or overeating, a result often capable of unhealthful consequences. The only safety is in learning self-control so that one's stimulated appetite may not lead on and on to gluttony.

SKIN

207. Skin Cleanliness. — The scientific reason for cleaning the skin, especially by the use of soap and warm water, is that it removes dirt, which is objectionable primarily because it is unæsthetic and therefore disagreeable to refined people, and secondarily, because dirt contains micro-organisms which may produce disease. In fact, dirty hands have caused typhoid and other dangerous diseases by leaving bacteria on dishes and on foods. Formerly it was supposed that a third reason for cleansing the skin with soap was to remove substances which "clog the pores of the skin and keep

in excretions"; but the skin has little to do with excretions except as water is incidentally eliminated while the skin is reducing the internal heat; hence "keeping the pores open" is a weak argument for cleaning the skin. The fact is that the pores "open" quickly, even on the dirtiest skin, when exercise develops excess of heat. However, we do not need the unscientific theory of "keeping pores open," for the æsthetic and bacteriological reasons named above are sufficient to convince any civilized person, and especially any one who sees the force of the rule, "use soap because refined people do so and the barbarians do not." This is more sensible than trying to show that soap is necessary for hygienic reasons, for there are healthy people who never or rarely use soap. Such health is not surprising, for soap has very much to do with æsthetics and little with health, except in possible bacterial infections.

The abuse of soap by many refined people deserves attention. Exposed parts of the body must be washed very frequently with soap, and preferably with warm water; but a complete bath with soap and warm water is taken too frequently by many persons. Soap removes the oily secretions and the warm water dilates the blood-vessels of the skin, increasing liability to colds. A warm soapy tub-bath once a week should be followed by cold water which causes contraction of the blood-vessels (§ 414).

As far as is consistent with cleanliness, soap with cold water, and especially cold water without soap, should be used daily on all parts of the body not exposed. The special reason for cold instead of warm water is given in the next paragraph.

208. Bathing as a Skin Tonic. — Above we have considered *bathing for cleanliness* only; but here we are interested in *bathing for health.* While only in removing bacteria does skin cleanliness appear to be necessary for health, we have

fortunately a very strong argument for daily bathing as a means of leading to healthy action of the skin blood-vessels, and indirectly of the whole body. For this purpose water should be much colder than the temperature of the body, and is best applied as sponge-bath, shower-bath, or plunge-bath (as in sea-bathing). Contact with the cold water first causes a reflex action leading to a reduced caliber of the skin arteries, and the skin quickly becomes pallid. A reaction follows brief exposure to the cold water, and the blood-vessels expand, the skin glows, and the bather feels stimulated. No such good effect comes from too long exposure, or in some cases when the water is too cold.

The explanation of the value of this cold bathing is that it gives the skin practice in readjusting its blood-supply when exposed to a low temperature. Many persons, especially those of sedentary habits, have skins which are not accustomed to react quickly to changes of temperature; and hence if chilled their skin arteries remain contracted, blood which ought to circulate in the skin is congested in some internal organ, inflammation develops, and a "cold" follows. Frequent practice in readjusting the blood-vessels, as given by cold bathing, will make the skin more likely to react and continue to receive its fair share of blood whenever exposed to low temperature, thus tending to avoid the dangerous internal congestions known as "colds." It should be noted that "colds" are not confined to the lungs and respiratory passages, for one may have an unrecognized "cold" from congestion of blood in other organs, especially in stomach, intestine, and kidneys.

If in spite of systematic cold bathing one's skin sometimes gets so chilled that it does not soon react, the normal circulation should be restored by ways suggested in § 203. To allow the skin to remain chilled for hours is dangerous.

Cold baths are best taken before breakfast, never within two hours after a meal, because the rush of blood to the skin interferes with the proper supply in the digestive organs.

209. Skin Foods, Hair-Tonics, Cosmetics. — All the much advertised "skin foods" are fraudulent, for only digested and assimilated foods supplied by the blood can build up the skin cells. Some of these foods are composed of epsom salts and coloring matter, the salts doing no good to the skin and the dye being possibly harmful. Others are chiefly colored vaseline or lanolin whose value can be no more than lubricants like pure vaseline at one-tenth the price of "skin food."

There are conditions when the scalp is made more healthy by tonics which reputable physicians prescribe; but the claims for most patent hair-tonics are absurd. At most, a hair-tonic can do nothing except correct diseased conditions of the scalp. Most people who use hair-tonics have no need of scalp medicine and they waste money in attempting to grow hair when they have a constitutional tendency towards thin hair.

Some of the patent hair dyes contain poisons. Various preparations for bleaching the skin, removing freckles, etc., are widely sold. Many of them are fraudulent and some of them dangerous. One complexion bleach which sells at $2 per bottle is borax in orange water and costs the manufacturers six cents to make. Some of the face bleaches contain poisonous compounds of mercury.

NERVOUS SYSTEM

210. Overwork and Sleep. — Unhealthy conditions of the nervous system are frequently the result of overwork, both mental and physical. Hence it is important that brain-workers should consider the hygiene of the nervous organs.

Regular mental work, as well as physical work, should be limited to a number of hours per day; and these should be the hours before late in the afternoon, when the maximum exhaustion of nervous force occurs. Nervous exhaustion from mental overwork is most often due to neglect of this rule; and the brain-worker should limit his regular day's work to a reasonable number of hours per day, and those when the brain is at its best. Too often mental overwork simply means such long days at intellectual tasks that exercise, recreation, and sleep are neglected. Sooner or later, this means the inevitable penalty of nervous disturbance, if not serious breakdown.

There come times in the lives of many brain-workers when some important work demands temporary nervous strain; but the man who is wise in the laws of hygiene will try to reduce the necessary strain to the minimum and to follow it with as much recreation as possible.

The importance of fads and avocations as a means to mental and physical recreation is great. Every man and woman should cultivate at least one hobby. Even collecting postage-stamps, coins, and natural-history specimens may be made an important daily relief to a nervous system tired by the regular day's work; but best of all avocations are those which are as far different as possible from the regular work, *e.g.*, a greenhouse, a garden, or a work-shop for a man engaged in mental work.

But overwork is not all due to excessive exercise of the nervous organs directly, for physical work may lead to nervous disturbance. This is obviously due to the fact that muscular contraction occurs only as the result of nervous action. Moreover, there may be the added effect of the wearisome monotony of uninteresting toil.

The close relation of muscular and nervous work points

to the important hygienic law that mental work should not be forced after physical exhaustion, or physical work after becoming mentally tired. The time for hard physical exercise is not near the close of a day of such intense mental strain that the tired nervous system seems to rebel at lashing the muscles into action. That is certainly a time to rest or recreate in any way which is not approached as an unpleasant duty. Conversely, the time for hard study is not at the close of a day of exhausting physical work. Whether mental work may safely succeed physical activity, or *vice versa*, usually depends upon whether one finds it possible to take up the change of work without constantly goading oneself against a feeling of exhaustion. Ambitious workers will not meet with the one great danger in this advice; namely, that of confusing real exhaustion and mere laziness.

Sleep. — Probably more important than any other rules of hygiene are those concerning sleep. Loss of sleep does far more damage than starvation. Men have voluntarily fasted 30, 40, and even 50 days, and afterward quickly regained their normal weight and health; but it is certain that a normal healthy man could not go without sleep so long. Sleep is a period of rest, repair, and growth, and is especially important for growing children. Much of the physical harm to children in crowded tenements is due to a combination of late retiring to rest, uncomfortable bedrooms, disturbed sleep, and early rising. Many a child in the poorer regions of great cities is anæmic, nervous, haggard in face, listless in school, sluggish at play; and the real trouble may be that he is not getting enough good sound sleep. This is likewise true of some adults, who should average seven to nine hours of sleep in each night. As far as possible, this should be taken during the quietest hours (10 P.M. to 6 A.M.) when the external stimuli tending to cause awakening are fewest.

MUSCULAR SYSTEM

211. Exercise for Health. — Those whose business or pleasure leads them to sedentary habits of life need to consider most seriously the question of physical exercise. The scientific reason for exercise is to be found in the coördination of muscular activity with all the other organs of the body, rather than in the development of the muscular system itself. In short, most people should exercise primarily in order to get reactions of the digestive, circulatory, respiratory, and nervous organs, while secondarily and incidentally they may develop their muscular systems. However, it is very doubtful, in the opinion of many qualified physiologists, whether excessive development of the muscular system is best for the general health of those who are not professional athletes or laborers. The well-known aphorism, "*Mens sana in corpore sano*" (a sound mind in a sound body), means that giant intellects *ought* to be located in healthy bodies in which all the functions are properly coördinated, and it should not be understood to mean that only one with the muscles of a champion athlete can hope to do great intellectual work. On the contrary, it is a remarkable fact that some of the greatest work in literature, art, and science has been accomplished by men and women who suffered from lifelong physical weakness. In such examples there is hope for all who are physically weak by nature. Athletic constitutions commonly originate congenitally and not in gymnasia.

The average man and woman, then, should exercise for health, deriving it from renewed activity of the organs that are closely coördinated with muscles, and from rest and recreation for the brain. This reference to the association of exercise and recreation is important, for we certainly

derive most benefit from exercise which is at the same time pleasurable and recreative. Herein is one great advantage of many forms of outdoor exercise over gymnasium work.

212. Excessive exercise is not beneficial when it leads to exhaustion; and severe over-strain may lead to injury of the heart, blood-vessels, or lungs. Athletic enthusiasts often answer this medical criticism against certain extra-strenuous games, such as football and rowing, by claiming that the moral gain from severe athletic contests overbalances the recognized danger of great physical harm from excessive exhaustion. That there is moral gain worth while in compelling tired muscles to obey to the point of exhaustion is extremely doubtful; and those who are fond of quoting that "Waterloo was won on the playing-fields of Rugby" should re-read history and note the victories in peace, and even in battles scarcely less strenuous than Waterloo, won by men whose moral fiber was certainly not directly traceable to previous athletic training on any school-playground. Moral qualities which make men great are inherent, not originated by any one form of activity; and hence we are not justified in excusing dangerously excessive exercise because one or more famous generals or other great men happened to play football, or some other game, when they were boys. There is no scientifically proved moral effect of physical strain which in the slightest degree militates against the hygienic rule that exercise for health should never be carried to extreme exhaustion. The world would have far more healthy and efficient men if this rule for muscular activity were more often applied both in work and in play.

PHYSIOLOGICAL EFFECTS OF STIMULANTS AND NARCOTICS *

213. Introduction. — Man has long been more or less accustomed to take into the body certain substances (alcohol, tobacco, tea, coffee, certain drugs, etc.) which are not properly classed with the ordinary food-materials, for their value as sources of energy and materials for repair is so slight as to be negligible. All these substances are conveniently grouped under the heading "Stimulants and Narcotics," which indicates that their action in the human body is either to excite or stimulate greater activity of certain organs, or to reduce their activity and tend to produce stupor or sleep (narcosis). Both the exciting action of stimulants and the quieting effect of narcotics are pleasurable to most people, and it is solely for this peculiar pleasure that mankind has adopted the habit of using the various substances which afford stimulating and narcotic effects.

214. Are Stimulants and Narcotics Needed? — It is interesting to note that no animal naturally makes use of any of the stimulants and narcotics; and hence it is often argued that the human species ought to be natural and avoid them. However, this is a rather weak argument, for in many other ways man has ceased to be natural (*e.g.*, cooking food is certainly unnatural for animals), and with advantage to himself. Clearly the use of stimulants and narcotics must be judged by their good or bad effects upon men, and not rejected simply because animals do not use them. The experience of animals indicates that man does not absolutely need stimulants and narcotics; but it has no bearing whatever on the question of whether man may or may not profit-

* To Teachers: See "Teachers' Manual of Biology," § 463, for notes concerning the use of this section.

ably make use of such substances. This will be discussed at various places in the following sections.

215. Examples of Stimulants and Narcotics. — Alcohol in small quantities appears to be a stimulant which increases the activities of many organs. It is well known that alcohol in large quantities produces a narcotic effect, leading to the complete stupor of intoxication. Many physiologists believe that even a small quantity of liquor containing alcohol has a narcotic, sedative, or depressing effect on the nervous system and through this influences other organs. Opium is well known as a powerful narcotic which quiets active organs, and in large doses leads to a fatal sleep. Most users of tobacco in any form claim that it has a soothing effect, *i.e.*, is a narcotic. Tea and coffee contain substances which are usually stimulating to most persons. Many drugs used by physicians (*e.g.*, strychnine, nitro-glycerine) are powerful stimulants, and are given in exceedingly small quantities. When powerful narcotics are demanded as relievers of pain, physicians commonly use opium and its products (laudanum, morphine).

216. Alcohol and Common Alcoholic Fluids. — The formation of alcohol from sugar will be described later in §§ 279, 280, which deal with fermentation caused by the yeast-plant. Practically any natural substance which contains starch or sugar may undergo fermentation. Thus juices expressed from grapes, apples, and other fruits, and the carbohydrates in grains of rye, corn, and barley, and in potatoes, are commonly used in producing alcoholic liquors, of which the chief varieties are mentioned below.

Malt liquors (beer, ale, and porter) are made from malt, which is made from sprouted barley grains. These are ground in water, and allowed to ferment. Hops are added and give a bitter flavor. Such a fermented liquor consists chiefly of

water, 1 to 8 per cent alcohol, and small quantities of other substances derived from the grains used.

Wines are juices of grapes which have fermented and produced 6 to 12 per cent of alcohol. Some wines are stronger (15 to 25 per cent) because brandy or strong alcohol has been added when bottling.

Distilled liquors (whisky, gin, brandy, rum) contain 30 to 50 per cent alcohol, and are made so strong by distilling the fermented fluids (water with rye, corn, oats, or potatoes for gin and whisky; molasses in water for rum; wines for brandy). Various flavoring and coloring materials are added to the distilled liquors. They differ essentially only in color, flavor, and proportions of alcohol. Some of the substances used to color and flavor are harmful, but are used in such small quantities that the alcohol is chiefly responsible for the physiological injury commonly done by the distilled liquors.

Alcohol in a more or less pure state can be made by redistilling and otherwise purifying any fluid in which fermentation has occurred. Since distilled liquors are nearly half alcohol, it is easily obtained from them. The grain alcohol of commerce is usually from 91 to 95 per cent pure; *i.e.*, it contains 5 to 9 per cent of water. A special quality for scientific purposes is about 99 per cent pure, and is very expensive to make.

Commercial alcohol is usually called "grain-alcohol," or, in chemical terms, ethyl alcohol. Wood-alcohol, or methyl alcohol, is commonly made from wood, and when taken into the human stomach is very poisonous. In all the discussions in this lesson, the word "alcohol" is used to mean grain or ethyl alcohol, for this is the characteristic constituent of the alcoholic liquors whose physiological effects are under consideration. The effect of alcoholic liquors is largely in proportion to the amount of contained alcohol, and so it

is justifiable and convenient to deal directly with the effects of alcohol and to neglect, temporarily, the minor fact that alcohol, as commonly taken in wine, beer, whisky, etc., is diluted with water and variously flavored.

217. Is Alcohol a Poison? — In popular usage, the word "poison" is associated with such powerful substances as arsenic, strychnine, snake-venom, and others which, when introduced into the human body, produce marked and even fatal disturbances.. In scientific usage the term is applied to many substances which cause demonstrable disturbance of any function of the body. There is no substance which is always a poison, for even strychnine and ricin may be diluted so as to produce no noticeable disturbance. A cup of coffee is not poisonous to an average adult, and yet it contains a greatly diluted dose of caffein, which in large amounts is a poison. Tea, coffee, ginger, pepper, and many other things taken with food contain small quantities of substances which in large amounts are poisons. Even common salt in very large quantities has proved a fatal poison. Evidently the word "poison" has a relative significance, and involves the quantity. In general, we apply it only to substances which in very limited quantity are harmful. The question, then, "Is alcohol a poison?" can be answered only by reference to the amount of alcohol and to the constitution of the individual who drinks it. That alcohol in large and intoxicating doses has proved fatally poisonous is well known, and that it commonly produces profound disturbances of various organs when used excessively and habitually is also common knowledge; but whether alcohol in very small quantities is a poison, as we commonly understand the word, is a difficult scientific question which only physiologists can answer by experimental studies made with animals and men.

A liter (nearly a quart) of whisky, gin, or rum given in one dose would kill any animal weighing 67 kilograms. (How many pounds?) Evidently alcohol in large quantities is a poison. However, even a victim of the alcoholic habit would not drink a quart of whisky within a short time. The question is whether in the smaller amounts, such as are commonly used by drinkers, alcohol is a poison. The next four sections discuss this question with reference to the organs of digestion, circulation, and respiration, and the nervous system; and it is pointed out that it is impossible to show by scientific methods that ordinary small amounts of alcohol produce effects comparable to those of the substances which druggists label "poison." Hence it must be concluded that, so far as we now know, alcohol in small amounts is not harmful enough to warrant labeling it "poison." We do not so label common salt, although a strong solution taken into the stomach has caused death; and while coffee contains a dangerous poison, a pot of the beverage should not be labeled as dangerous. Most people would be misled by such a label, for they know well that in ordinary quantities common salt and coffee produce no symptoms of poisoning. Likewise, in very limited quantity alcohol is not a poison in the sense that we understand various drugs to be poisons. However, while alcohol is not a poison to be labeled as druggists label the common poisons, it produces very harmful effects on human organs. Nothing is to be gained by saying that alcohol is a poison when we mean that it is injurious.

218. Effect of Alcoholic Liquors on Digestion. — When taken into the stomach, alcoholic fluids cause a marked increase in the flow of gastric juice from the glands of the stomach wall. There is also an increase in the amount of the constituents of gastric juice; namely, pepsin and hydro-

chloric acid. Wine, alcohol, beer, whisky, brandy, and mixtures of these stimulate the gastric glands in this way. The alcohol quickly leaves the stomach, being absorbed into the blood, leaving the gastric juice in concentrated form. Whether such an effect of alcoholic fluids upon gastric secretion is directly harmful or not seems to depend upon the amount of alcohol present. Thus strong beverages, like brandy, gin, and whisky, with 40 to 50 per cent of alcohol, retard the digestive action of pepsin on proteids; but this effect depends upon the amount of alcohol taken, the amount of food in the stomach, the strength of the gastric juice, and the health of individuals. Hence it is impossible to lay down any absolute rule as to the minimum quantity of alcohol which will harmfully affect digestion in the stomach. It is certain, however, that large drinks of alcoholic beverages do impede gastric digestion even in healthy individuals; and since the alcohol does no particular good, it is wisest not to run the risk of unhealthful effects upon digestion.

It should be emphatically stated that the effect of alcoholic drinks upon digestion is not solely due to the amount of alcohol in them. Thus sherry wine with 20 per cent of alcohol retards digestion much more than does an equal quantity of 20 per cent pure alcohol. Large amounts of claret wines have a similar, but less noticeable, effect. The same is true of ale, beer, and other malt liquors. When any of the wines and malt liquors are used freely with meals, there is likely to be a considerable retardation of the digestive processes.

Concerning the effect of moderate amounts of alcoholic fluids upon gastric digestion, it appears from experiments made by competent investigators that the greater secretion of gastric juice is counterbalanced by the retarding effect; and hence, as a rule, there is no reason for or against using

small amounts with meals, so far as the effect on gastric digestion is concerned. But we shall see later (§§ 221, 223) that alcohol affects other organs so harmfully that one should decide against its use as a beverage.

219. Effect of Alcohol on Blood-System. — Small quantities of whisky or other strong alcoholic drinks, as used by some physicians in cases of great depression of the heart, stimulate that organ reflexly through the nervous system. In large and intoxicating quantities alcohol is a direct and powerful depressant of the heart, weakening the beat, distending the cavities, and diminishing the pumping of blood. Herein is the scientific reason for the advice not to use large and depressing quantities of alcoholic fluids for snake-bites.

It is well known that alcohol in even small amounts causes flushing of the face and a sense of heat over the skin. This is due to the dilation of blood-vessels. Habitual use of alcohol very commonly leads to permanent dilation of the facial blood-vessels.

The combined effect of large quantities of alcohol on heart and blood-vessels is to lower the pressure of the blood.

Whether these effects are decidedly harmful depends upon conditions, especially of organs other than the blood-system. It is a significant fact that most modern physicians are careful in prescribing alcohol, even in moderate doses, when there is need of stimulating effects upon the heart and blood-vessels; for the harmful effects on other organs may more than counterbalance any possible good done to the organs of circulation by alcohol used as a medicine.

220. Alcohol and Respiration. — For a short time after drinking alcoholic fluids there is an increase in the rate of breathing. This is probably due to an increased loss of heat from the dilated blood-vessels of the skin. In other words, the respiratory organs must work faster in order to

supply oxygen for the increased internal oxidation needed to supply heat in place of that lost. Such a chain of events leads many great physicians to believe that harm will come from a dose of alcohol, when as in pneumonia there is weakened heart and lungs already congested with blood. At any rate, it is exceedingly doubtful whether in conditions of health any useful purpose is served by increasing respiration by means of alcohol; and hence so far as effect on breathing is concerned, healthy people will be safest by avoiding alcohol in any form.

221. Alcohol, Nervous Organs, and Muscles. — The general influence of large amounts of alcohol upon the nervous and muscular systems is well known to all who have observed the actions of drunken men.

Alcohol tends to lessen all mental activities. Careful experiments have shown that even a pint of wine diminishes acuteness of smell and touch and interferes with the power of the eye to estimate measurements. Psychologists have failed to prove that alcohol ever increases the quantity and vigor of mental operations; on the contrary, even small doses tend to lessen reasoning power. Larger quantities affect the power of attention, judgment, and reason, render the senses less acute, and exert an anæsthetic action which leads to the sleep characteristic of intoxication. Study of many such conditions leads eminent experts on drugs to the opinion that, even in moderate quantities, alcohol tends to have a sedative or narcotic action on the brain. In connection with this statement, may be cited the undoubted fact that alcohol regularly used during the day's work diminishes the amount and quality of work done. This has been experimentally proved by tests with type-setters and others whose work is of such a nature that it is easy to compute both speed and accuracy. Those who command armies and

large groups of men engaged in physical labor agree that the use of alcohol during work decreases effectiveness. This is probably because of the sedative action above mentioned.

It has not yet been possible for investigators to collect and collate the facts as to the effect of small amounts of alcoholic liquors upon large numbers of brain-workers (lawyers, teachers, clergymen, business men, physicians), for the reason that many will not or cannot answer questions concerning their own experiences with alcoholic drinks. One list of 892 brain-workers in the United States showed 167 total abstainers, 579 occasional drinkers, and 146 moderate drinkers. A large number of the moderate drinkers expressed the opinion that the use of alcoholic drinks gives bad results as stimulants to mental work, and many also stated that they used alcohol *from habit*, and with no expectation of being enabled to do more or better mental work.

In spite of the fact that we cannot say definitely how little alcohol will seriously interfere with the normal functions of the nervous system, it is clear that *the brain-worker acts most wisely by avoiding alcohol.* Moreover, it cannot be repeated too often that all people will probably gain in both physical and mental efficiency if they avoid alcohol altogether, because the *possible accumulative effects* of the frequent use of small doses of alcohol are still unknown to science.

Alcohol in Muscular Work. — Just as alcohol tends to depress the activities of various organs, so it acts on the muscles. It does not increase the power for hard muscular work, and in numerous observations by commanders of soldiers and of other groups of men it has been found that alcoholic drinks are opposed to the most efficient muscular work. Men can do far harder and better work under the stimulating influence of such harmless hot beverages as beef

tea, chocolate, malted milk, and plain milk than they can do when depending upon alcohol for stimulation of tired nerves and restoration of weary muscles.

222. Nutritive Value of Alcohol. — "Is alcohol a food?" The answer depends upon what we understand by food. It is not food in the sense that bread and meat are foods, for it cannot support life. It lacks the nitrogen and necessary mineral elements for growth and repair. But it may, in very small quantities, take the place of foods used for fuel or energy, for some is oxidized in the human body.

However, it is of little moment that alcohol has a very slight food value, for against it there are serious objections as follows: (1) Only small amounts of alcohol can be used as food; and it is easy to overestimate the amount which is safe. (2) There is a peculiar tendency to excessive and habitual use. (3) Its action as a harmful drug is likely to overbalance its slight value as food. (4) It is a very expensive food as compared with carbohydrates and fats, which can supply equivalent energy.

Such grave objections to alcohol in any liquors make it necessary to regard its food value as of no practical importance. One of the best of advanced books on physiology well summarizes the whole matter as follows: "Only in very exceptional cases can alcohol have any practical importance as a nutriment. It is especially in the case of acute diseases accompanied by diminished digestive power that alcohol seems to serve as a valuable nutriment." However, it is only fair to say that many doctors never prescribe alcohol.

After all, no one regularly uses alcohol as food, but rather for its peculiar taste and stimulating effect. The use or disuse of alcohol must depend upon the answer to the question, "Is the stimulating effect of alcohol injurious?" *Except in small quantities it certainly is an injurious stimu-*

lant; and no one can safely estimate the quantity which may not lead to accumulated effects, or to habits of excess.

223. Disease Effects of Alcohol. — Many organs are known to become diseased as the result of long-continued excessive use of alcoholic drinks. Liver, kidneys, heart, blood-vessels, and nervous organs are frequently involved in disease changes. *All medical men recognize that alcoholic intemperance leads to an immense amount of sickness.* A large number of deaths are due to the diseases known as chronic alcoholism and delirium tremens (a kind of temporary insanity); and many cases of Bright's disease of the kidneys, paralysis, pneumonia, tuberculosis, and many other diseases are believed by eminent physicians to have been hastened to a fatal issue by the previous use of alcohol.

It should be noted that no reputable physician claims that even excessive use of alcohol will *always* lead to diseased conditions. There are exceptional individuals who are almost constantly intoxicated, and yet show no external evidences of diseased organs. However, no sane person who has learned of the great liability of excessive drinkers to diseases will care to take his chances of being one of the few who appear to escape the most serious consequences. Moreover, it should be noted that in recent years there have been found many cases of diseases in "moderate drinkers" which are probably due to long use of alcoholic liquors. These are the reasons why the great life-insurance companies favor total abstainers.

It is well known that the excessive use of alcohol leads to obesity or storing of fat. This is most dangerous when in the muscles of the heart. Gout is often, not always, caused by alcoholic liquors.

224. "Pure" Alcoholic Beverages. — Manufacturers of alcoholic liquors often advertise that their products have

been "purified" so that they have no harmful action. This is an *absolutely false* claim, for scientific studies have shown that while the so-called "impurities" in alcoholic drinks are poisonous, they are present in such small amounts that their effect is slight, and that the harmful effect of alcoholic liquors is *chiefly due to the alcohol* they contain. Even absinthe and other highly flavored French liqueurs, containing extracts of wormwood, anise, and other aromatic herbs, certainly owe most of their decidedly harmful action to their large amount of alcohol (50 to 80 per cent). Alcohol in large quantities has been demonstrated to be poisonous enough to account for most of the physiological evils ascribed to alcoholic drinks. So long as people will drink alcoholic fluids, there should be "pure food" laws aimed at making them as free from poisonous substances as possible; but no one should be deceived by claims that a given brand of liquor is harmless. Whenever alcohol is present in considerable amount, there is a substance which, in a quantity varying with individuals and conditions, is certain to be harmful in its effect upon the essential life-processes.

The common opinion that the cheap artificial whisky sold in some saloons for three cents a glass is especially injurious to health as compared with "high grade" natural whisky made from corn and rye is not supported by chemical analysis. This cheap whisky consists of 30 to 50 per cent alcohol with caramel, sugar, and flavoring essences. Its harmfulness depends chiefly upon the alcohol contained. Perhaps the chief reason why such cheap liquors appear harmful is that the low price leads to the use of two or three times more alcohol. Certain it is, however, that the chief danger *in cheap whisky, and in all whisky,* lies in the 30 to 50 per cent of alcohol which it contains.

225. Alcoholic "Temperance Drinks." — Very many

people who hold strictly to temperance principles are unaware that many fluids sold at drug-stores contain large amounts of alcohol. In general, all "tonics," "bitters," "malt-extracts," "celery compounds," and other similar fluids advertised as givers of strength, vigor, etc., contain alcohol. Certain much-advertised medicines called "sarsaparilla" contain at least 25 per cent of alcohol. Many "bitters" and "tonics" contain from 15 to 45 per cent of alcohol. Some of these were formerly advertised as containing no alcohol, or as "temperance" medicines; but the present drug law compels manufacturers to print on the label the amount of alcohol and other drugs which may be very injurious.

Root-beers, ginger ale, and fermented milk contain very small amounts of alcohol, usually less than one per cent. So-called "sweet cider" sold by all dealers may have more alcohol than the average beer, and frequently contains 0.2 to 3.5 per cent. "Hard" or fermented cider contains 4 to 8 per cent of alcohol, and therefore compares with mild wines and strong beer.

226. Alcohol as Medicine. — Concerning the value of alcohol in treating diseases, great authorities on medicine do not agree. There are many eminent physicians who never prescribe it, but prefer to use drugs whose stimulating action is more definite and certain than that of alcohol. Other equally eminent doctors hold that alcohol is of great value in certain acute diseases where there is a tendency toward general and heart weakness. On the whole, there is a marked tendency towards dropping alcohol from the list of valuable drugs.

227. Alcohol and Growth. — It is universally admitted by physiologists that all *alcoholic drinks are deleterious to growing individuals,* and this means the first eighteen or

twenty years of life. It is absolutely pernicious to young children. And in addition to its direct physiological injury to young people, there is the oft-demonstrated *tendency to excessive use.* The vast majority of habitual drinkers of alcoholic liquors begin in early life.

228. Summary of Effects of Alcohol. — Professor Atwater, the famous chemist, who contributed much to our knowledge of foods and their uses, wrote that in his personal opinion "people in health, and especially young people, act most wisely in abstaining from alcoholic beverages."

A committee of five prominent American physiologists has thus summarized the facts regarding the use of alcoholic drinks: (1) They are not needed by young and healthy persons, and are dangerous to them in so far as they tend to create a habit. (2) In certain cases of disease and weakness they are useful in quantities to be prescribed by physicians. (3) Alcoholic drinks of all kinds are worse than useless to prevent fatigue or the effects of cold, although they may at rare times be useful as restoratives. (4) They are almost always a useless expense. (5) Their use in excess is the cause of much disease, suffering, and poverty, and of many crimes.

229. Effects of Tobacco. — Concerning the effect of tobacco in its various forms upon health, there has been much discussion. As is well known, the stem and leaves of the tobacco plant contain a poisonous substance known as nicotine, which, in concentrated doses, quickly kills small animals. However, this proves nothing regarding the effect of smoking tobacco, or of the disgusting habit of chewing it, which is now almost unknown among the better classes of people; for in both of these ways of using tobacco the nicotine is exceedingly diluted, as is the poison found in tea and coffee. The result is that the effects of tobacco are not

marked, and so even physicians are not always certain as to its influence upon their patients. The best established knowledge we now have is that indigestion, irritation of the respiratory organs, and heart and nervous disturbances may in some people result from the use of tobacco, while others show no apparent effect.

All this refers to healthy adult men, for all medical authorities agree that tobacco is *always harmful to growing boys,* and interferes with their physical and mental development. All schoolboys know how rigidly most athletic trainers forbid the use of tobacco by those in training.

The direct effect of tobacco is narcotic, and many smokers say that it "soothes their nerves." It is very doubtful whether the nerves would need "soothing" if the tobacco habit had not been established. Opium also has such an effect; but it is well known that the craving for the soothing is the result of the established habit, and those who never used opium do not need to be soothed by that drug. Likewise, those who have never acquired the tobacco habit appear to have no need for its narcotic or soothing effect. The difference between the opium and tobacco habits is in degree, not in kind. Both create a demand or craving for their peculiar narcotic effects.

The eyes of a few people are seriously affected by even small amounts of tobacco, while many find that tobacco smoke irritates the eye-membranes and causes some blurring of vision.

The whole physiological truth about tobacco so far as now known is that: (1) no one needs it except to satisfy an established habit; (2) many adults are injured by it, and no one knows just how much will do harm to a particular person; (3) some adults are apparently not harmed by limited use; (4) it is decidedly injurious to growing boys; (5) those who

avoid establishing the habit in youth do not as a rule care to learn later, for there are no physiological reasons why any one should deliberately set out to learn the use of tobacco in any form.

230. Effects of Tea, Coffee, and Cocoa. — The first two are most important because they are so widely used as beverages. It is now well known to physicians that many people drink too much tea and coffee, and that temperance is needed in use of these beverages no less than with alcoholic drinks. Their stimulating effect is due to the presence of a powerful drug (caffein), which has a stimulating action on the nervous system. Nervousness, insomnia, headache, and indigestion are common symptoms arising from excessive use of tea or coffee; and disturbances of other organs may follow. One who uses even small amounts of tea and coffee and who does not "feel well" for no apparent reason, should try the effect of completely abstaining for a few days occasionally. By so experimenting with themselves, many people have learned that tea and coffee harm them. Other people are certainly benefited by a limited use of these beverages.

Tea and coffee should never be given to young children. They may be harmed by such stimulants.

Cocoa and chocolate are made from the seeds of the cacao- or chocolate-tree, a native of tropical America. The seeds are rich with 50 per cent of fat, some of which is extracted in the process of making commercial cocoa or chocolate. Both of these contain a substance similar to the caffein of tea and coffee, but much milder in its effect. One who has difficulty from the use of tea and coffee will do well to experiment with himself and thus learn whether chocolate or cocoa produces marked effects.

231. Effect of Narcotic Drugs. — We are here concerned with the effect of such drugs as opium, morphine, cocaine,

laudanum, chloroform, chloral hydrate, and various patent or secret preparations, all of which are habitually used by some people. In most cases, such drugs are used first to narcotize the nerves and thus relieve pain, and their frequent use finally becomes a habit even more powerful than the alcoholic habit. It is unnecessary to go into an extensive discussion of narcotic drugs, for most intelligent people now understand that only on a physician's advice is it safe to use any drug to relieve pain; and also that no drug should be used so frequently as to offer the grave risk of establishing a habit.

It should be noted that the narcotic drugs do not cure diseases. For example, patent headache powders and pills simply dull the sensory nerves. The headache may be due to a disordered stomach, eye-strain, constipation, or other causes; and hence the narcotics give only temporary relief. Obviously, it is wiser to consult a doctor, who may be able to find the cause of the disorder and prescribe treatment.

The remarks made above concerning narcotic drugs might well be applied to habitual taking of any kind of medicine without a physician's advice. An immense amount of harm is done by the thousands of patent medicines. Very few of them are useful medicines, and all are sold at exorbitant prices.

CHAPTER X

ORGANISMS THAT AFFECT HUMAN HEALTH

I. PLANTS THAT AFFECT HEALTH

232. Seed-Plants. — It is well known that many of the seed-plants are poisonous. Some of these, such as the three-leaf ivy, poison oak, and swamp sumac, produce in their leaves and stems irritating substances which often cause serious inflammations of the human skin. Many other common seed-plants are poisonous when taken into the alimentary organs, because they contain substances which are absorbed into the blood. These substances are often extracted and in small quantities used in medicine, *e.g.*, strychnine, from a Java plant, aconite from monk's-hood, atropin or belladona from the deadly nightshade.

Laurel leaves and wilted wild cherry leaves are known to be poisonous to some farm animals. Several pamphlets published by the United States Department of Agriculture deal with poisonous plants.

233. Mushrooms. — The wild species of mushrooms and toadstools are not commonly used as human food because of the difficulty of distinguishing with certainty between edible and poisonous species. There is no safe general rule; and botanists who have specially studied mushrooms advise that no species should be eaten unless cautiously identified. Especially should people avoid mushrooms with a ring or cup at the base, for this is one mark of the deadly Amanita, one of the most poisonous plants known to science. Atkin-

son's "Mushrooms" and Marshall's "Mushroom Book," and the pamphlets "Mushroom Poisoning" and "Edible and Poisonous Mushrooms" (both issued by the United States Department of Agriculture) give pictures and descriptions of many species pronounced edible. But even with these guides to identification one should be *exceedingly cautious* before deciding to eat a mushroom which resembles those said to be poisonous.

(*D*) Exhibit pictures and specimens of any available edible and poisonous mushrooms. Especially should attention be called to the Amanita. Mushrooms are easily preserved in 3 to 5 per cent formalin in water.

234. Molds. — The common molds (§ 272) which grow on various foods are not known to be harmful if small quantities happen to be eaten; but the discovery that moldy meal and other foods cause illness of chickens, cows, and other animals suggests that moldy or musty foods should always be rejected as unfit for human use. Some physicians believe that pellagra, a disease which is common in our southern states, is caused by molds in cereal grains used as food; but the exact facts are not yet known. Some skin diseases (*e.g.*, ringworm) are due to mold-like plants growing just beneath the surface of the skin. The spores of such plants are commonly distributed by towels, sponges, combs, and barber's tools. These articles are easily sterilized by means of soap and hot water.

Laboratory work on molds is given in § 272.

235. Algæ. — Simple plants belonging to the group of the Algæ (§ 283) sometimes grow very abundantly in reservoirs and tanks used for storing water, and impart a very disagreeable flavor and odor to the water. In some of the late summer months of recent years the great Croton Lake that

supplies water to New York City has been polluted by these plants. They produce no directly poisonous substance in the water; but affect health as do many other disagreeable substances that influence appetite and digestion.

236. Microscopic Plants. — Man has long since learned most of the larger poisonous plants which may affect health; but only within the past half-century has it been discovered that some of the microscopic plants are the causes of the most destructive diseases. These simple plants belong chiefly to a group known as the *bacteria*, and the science devoted to them is *bacteriology*.

Bacteria

237. Bacteria, Germs, Micro-organisms, Microbes. — The word bacteria (singular, bacterium) is the biological name of a group of the simplest one-celled plants. Popularly, the four terms which stand in the above heading are used as if synonymous; but the fact is that the last three may properly be applied to some microscopic organisms which are not bacteria, and in certain cases are one-celled animals (§ 258). In other words, the last three are general words meaning microscopic organisms; while bacteria are a special kind of such small organisms, belonging to the plant kingdom. Sometimes it is very convenient to have the general terms. For example, the malarial germ (an animal) and the typhoid germ (a plant — bacterium) both cause disease. Both are *micro-organisms*.

238. Study of Bacteria. — (*L* or *D*) Clean, by washing with soap or soap-powder and rinsing, some small bottles or test-tubes and plug with cotton. Place the plugged tubes in a sterilizer (§ 245 in "Applied Biology") and keep the water boiling for a half hour. Protect the tubes from dust until needed.*

* To Teachers: Concerning plugging tubes and sterilizing, see the "Applied Biology," § 245.

Any clear soup or bouillon will serve for the following experiment. The clear concentrated soups commonly sold at ten cents per can may be used after diluting with water. Test with litmus-paper, and if acid add some baking soda (or caustic soda solution), little by little, until the soup is slightly alkaline in reaction. When thus prepared, the bouillon may be kept in a bottle or flask by simply plugging the mouth with cotton and sterilizing after each opening of the bottle.

Fill sterile test-tubes half full with the bouillon; and replace the cotton plugs, taking care that they do not become wet. Place the tubes in the sterilizer for a half hour, and repeat on the following day. The sterile tubes may now be kept indefinitely. It is best to keep them covered so that dust from the air may not fall on the cotton and thus increase the chance of bacteria getting into the tube when the plug is removed.

Examine tubes which have remained sterile for many days. If bacteria develop, the bouillon will become turbid or cloudy.

Take the plugs from some tubes with bouillon, and leave them open for several days. Do bacteria develop? What is the explanation of the fact that plugged tubes remained sterile? The cotton certainly cannot keep air out of tubes; what then can be its effect on the air which enters the tubes?

Mount a drop of bouillon from a tube which has become turbid. It is well to have some cotton threads under the cover-glass to assist in finding the focus. Examine with a high power. Look for exceedingly minute, transparent bodies, much smaller than yeast cells and mold spores; some rod-shaped, some spherical, some twisted rods (Fig. 71). By shifting the mirror of the microscope, it is possible to see them better. Some of these organisms (*bacteria*) swim rapidly by means of cilia so small that they cannot be seen with the ordinary microscope. Watch the swimming of some of the largest bacteria visible. Remember that the apparent rate of speed has been magnified as much as have the bacteria, and that the distance apparently covered must be divided by the magnification of the microscope used in order to learn the actual speed. Glass slides

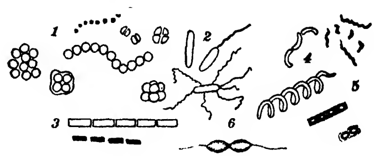

FIG. 71. Various forms of bacteria. *1*, micrococci; *2*, bacilli with cilia; *3*, chains of bacilli; *4*, spirilla; *5*, bacteria with spores; *6*, dividing bacterium.

with delicate ruled lines have been used to estimate the size and speed of the bacteria. Some of those often seen are so small that 50,000 placed end to end would make a row one inch long, and a bacterium $\frac{1}{1000}$ of an inch long belongs to a giant species.

In order to make bacteria more distinctly visible, it is customary to stain them. A simple method is described in § 255 of the "Applied Biology."

Make brief examination of bacteria obtained from various sources, such as sour milk, "mother-of-vinegar," and any organic materials found in a state of decomposition. All bacteria seen will be spherical, rod-like, twisted, or spiral in shape, but they may be found united in groups.

Bacteria may be found which show an enlargement due to the formation of a *spore*. These spores appear as dark spots when the microscope is slightly out of focus, and very glistening when in focus. "Hay-tea," made by pouring hot water over some good hay, and filtering through a layer of cheese-cloth, is excellent for growing bacteria for study of spores. Fill several test-tubes half full of "hay-tea," plug with cotton, heat to 100° C. by holding tubes in gas-flame until boiling occurs, or keep them for a short time in a sterilizer. Sterilize half of the tubes again on second and third days. The tubes sterilized once will probably become turbid within a few days and microscopic examination will show that practically all the bacteria present are rod-like. Later they will form spores; and this is the secret of the bacteria appearing after once boiling. The spores were able to withstand the heat; but before the second or the third heating they had germinated and the bacteria thus formed were killed by the later heating.

Pure Cultures of Bacteria. Gelatin plates. (*D*) The teacher will explain these two topics. Reference: "Applied Biology," § 255.

239. Important Facts concerning Structure and Functions of Bacteria. — (*a*) *Size.* — The average rod-shaped bacteria are not more than $\frac{1}{10000}$ of an inch in length and $\frac{1}{50000}$ in diameter. Many of the spherical forms are not more than $\frac{1}{50000}$ of an inch in diameter; some are still smaller and just visible with the highest powers of the microscope, and the germs (supposed to be bacteria) of the foot- and mouth-

disease of cattle are so small that they will pass through the pores of the earthenware tubes in a Pasteur-Berkefeld filter, which removes all bacteria large enough to be seen with the microscope. In fact, bacteria are so small that fractions of inches are inconvenient measures; and biologists commonly state dimensions in micromillimeters or microns, one of which is $\frac{1}{1000}$ of a millimeter, or about $\frac{1}{25000}$ of an inch. A bacterium $\frac{1}{25000}$ inch long would be 1 micron long.

(*b*) *Growth and Division.* — Under favorable conditions, a bacterium rapidly grows to full size and then divides into equal halves. Each of these absorbs food, grows, and soon divides again. Certain bacteria have been observed to divide every twenty minutes. Some one has computed that if the descendants of a single individual bacterium were to keep on dividing once an hour for two days there would be more than 280 millions. You can easily verify these figures by applying the mathematical formulas for geometrical progression. At the rate of one division every half hour, there would be 4772 billions in 72 hours, and the weight would probably be more than 7000 tons. These figures simply illustrate the enormous reproductive powers of the bacteria and help us to understand how a few bacteria introduced may soon produce enough to cause disease or the decomposition of foods. But the truth is that the half-hour or hour rate of division is never maintained for long at a time. Soon food-supply is exhausted, their own excretions accumulate and exert a poisonous influence, and such unfavorable conditions tend to check the rapid rate of growth.

(*c*) *Spore-formation* occurs in some bacteria. Only a few human diseases, and those not very common, are caused by bacteria which produce spores. This is a fortunate circumstance, for, as we have seen, spores are much more difficult to kill than are the active bacteria. As a rule, one bacterium

produces only one spore, and this germinates and forms one bacterium. There is therefore no multiplication, and spore-formation is simply a device for adapting the bacteria to unfavorable conditions. Spores taken from cattle dead from the anthrax disease have been found capable of germinating many years after the animals were buried.

(*d*) *Temperature.*—Some bacteria are able to multiply near the freezing point, and some live in hot springs in water at a temperature which will kill most kinds of bacteria and other living things. Between these two extremes there are all gradations. Contrary to the popular belief, freezing does not kill all bacteria. Bacteria of several species, including those which cause typhoid and diphtheria, have been kept several days at the temperature of liquid air (about $-190°$ C.), and when thawed out, have appeared to multiply normally. However, a very large percentage of common bacteria die when frozen in ice, and comparatively few are living after the ice has been kept five or six months. A few years ago an epidemic of typhoid fever was traced to ice that had been stored seven months, so that all ice from waters contaminated with sewage should be regarded with suspicion. While most of the bacteria will probably die, the few which remain may multiply rapidly when taken into the human body.

The thermal death-point of bacteria varies. Ten minutes exposure to a temperature of 70° C., or one minute at 100° C. (boiling), will kill all bacteria of typhoid and tuberculosis. Spores of other bacteria may survive the boiling point for hours; but boiling for a short time on successive days (known as discontinuous sterilization) will cause the spores to germinate, and then they are easily killed by heat. Fortunately, the disease-producing (*pathogenic*) bacteria likely to be in drinking water and milk do not form spores.

Sterilization of substances containing bacteria is usually accomplished, as described for molds (§ 273), by discontinuous steaming or boiling on two or three days. The first boiling (100° C.) swells the spores, and the later heating kills them. Steam under about 30 lb. pressure and having a temperature of about 130° C. will kill even resistant spores in half an hour. Dry hot air at about 350° C. is also efficient as a sterilizer of such articles as clothing.

Pasteurization (discovered by Pasteur) of milk means heating it to a temperature of 60 to 70° C., and keeping at this temperature for 10 to 20 minutes. It does not change milk as does heating to boiling (100° C.), but it kills the disease bacteria likely to be present in impure milk.

(*e*) *Light.* — Strong sunlight kills all bacteria which are directly exposed, as on the surface of soil. Some species are killed in a few minutes, and few can withstand hours of exposure. This is important, for it suggests the value of sunlight for killing bacteria in rooms, and especially on clothing, carpets, etc., which can be exposed out-of-doors. It also suggests the importance of building houses so as to get the maximum of sunlight; for example, shade trees should not stand too near houses. The value of sunlight in disinfecting streets cannot be too strongly emphasized. Sprinkling with water increases the germicidal action, for wet bacteria stand less light. It is unfortunate that all main streets in cities cannot be in the north-south direction so that all their surfaces will get the full force of sunlight at mid-day.

(*f*) *Chemicals.* — Many chemicals kill bacteria, and are called *germicides* or *disinfectants*. Some chemicals which do not kill bacteria but prevent their multiplication are called *antiseptics*. Corrosive sublimate (mercuric chloride) and carbolic acid are two powerful germicides. Most strong acids and alkalies are also germicides. Chloride of lime and

washing powders are efficient germicides for general household cleaning. The proprietary disinfectants advertised in the magazines are too expensive and some of them are frauds. Sulphur gas from burning sulphur and formaldehyde are commonly used for disinfecting rooms. Formalin is now used more than sulphur, because it does not bleach colored articles and is not so poisonous to human lungs. It is easily evaporated in a room either by a special lamp or by the heat generated in slaking lime on which formalin is quickly poured before closing the door of the room. A still more effective method for fumigation consists in mixing 1 ounce of paraformaldehyde with $2\frac{1}{2}$ ounces of potassium permanganate and then adding 3 ounces of water before sealing the door of the room. This will disinfect a room of 1000 cubic feet in four hours. Cultures of bacteria exposed in such rooms are killed by the gas generated. Among common antiseptics are very dilute solutions of formalin, carbolic acid, boric acid, common salt, and many substances produced by plants (menthol, thymol, eucalyptol, camphor, cloves, cinnamon, etc.). The preservative action on foods of common salt, vinegar, creosote (on smoked meats), and spices is due to the antiseptic power of these substances. The more powerful preservatives, such as boric acid, sodium benzoate, formalin, and salicylic acid, are sometimes used in foods; but there is danger of injuring the digestive organs by amounts so small that the sense of taste does not guard against them, as it does against excess of vinegar and common salt. Hence, the food laws and reliable producers of canned foods are opposed to the use of the above-named chemicals which might be unhealthful in quantities that the consumer could not detect.

240. Where Bacteria are Found. — They may be said to be almost ubiquitous. They are abundant in soils; water

of seas, rivers, and lakes; in the bodies of animals and plants; in all dead organic matter in nature; and in the air (except on high mountains, in polar regions, and in uninhabited desert areas of such immense size that living bacteria could not be carried on dust from other regions). In fact, bacteria are distributed wherever they can get food and proper temperature for growth and multiplication. Unlike other organisms, certain bacteria do not require oxygen from the air, for they can get it by decomposing the organic substances on which they live. Such bacteria are called *anaërobic* (living without air). Some of these can live deep in the soil; but at depths below where roots of plants and earthworms penetrate, the soil is usually without bacteria. Hence, water from deep wells is usually pure, unless there are openings between strata which somewhere communicate with lakes or other surface water.

The wide distribution of bacteria, especially on or in everything connected with the inhabited surface of the earth, makes it extremely difficult to eliminate them. In fact, only in closed vessels, etc., in which all bacteria can be killed by heat or chemicals, is it possible to keep any substance free from bacteria (*i.e.*, sterile). This is the reason for the careful work necessary in preserving many foods.

241. Diseases Caused by Bacteria. — We are so familiar with the idea that many diseases are caused by "germs" or bacteria, that it seems scarcely possible that less than thirty years ago no disease had been shown to result from the growth of bacteria in the human body. It was in 1876 that Robert Koch, of Berlin, made pure cultures of rod-shaped bacteria found in the blood of cattle and sheep suffering from anthrax, or splenic fever, and gave the first proof that bacteria cause disease. Six years later (1882) Dr. Koch demonstrated beyond question that human tuber-

culosis is caused by a bacterium which he named Bacillus tuberculosis; and in 1883 he proved that the dreaded disease, Asiatic cholera, is caused by another specific bacterium. These discoveries aroused the interest of many investigators, with the result that in less than thirty years there has been built up the new science of bacteriology, which has already been of inestimable benefit to the human race and bids fair to lead soon to absolute control of some of the most dangerous diseases.

To-day the list of diseases known to be caused by bacteria is a long one and each year becomes longer. The following are some of the best known: tuberculosis of any organ, cholera, diphtheria, typhoid fever, blood-poisoning, pneumonia, meningitis, influenza, tetanus, leprosy, bubonic plague, and numerous others of rarer occurrence. These are all *infectious*, or germ diseases; and some of them are also *contagious*, or liable to be transmitted by contact with patients.

242. Diseases Caused by other Micro-organisms. — A number of diseases are now known to be caused by micro-organisms which are animals. These animal parasites are one-celled, and belong to the group of the Protozoa (§ 115). The terrible African disease known as sleeping sickness, malaria, and a form of dysentery are the best-known human diseases certainly due to animals which produce effects similar to those of bacteria in other diseases.

243. Infectious Diseases not yet Understood. — Other diseases are almost certainly due to micro-organisms which are readily transmitted from one person to another, thus making them infectious; but the organisms have not been discovered. The diseases of unknown causation are yellow fever, hydrophobia, smallpox, whooping-cough, measles, scarlet fever, and mumps. The last five of these

infectious diseases are highly contagious. In all these diseases it has been possible for medical men to do much towards controlling their spread by working on the assumption that some undiscovered micro-organism is the cause, and that therefore cases of these diseases should be handled according to principles based on diseases known to be caused by bacteria. For example, yellow fever has been shown to be transmitted by bites of certain kinds of mosquitoes which have previously sucked blood from a yellow-fever patient; and this has suggested the desirability of applying the rules first worked out when it was discovered that malaria is caused by microscopic animals which are injected into human blood by mosquito bites. The rules simply require destroying of the mosquitoes (§ 260), or preventing them from biting healthy persons and especially those sick with malaria or yellow fever. Similarly, in dealing with smallpox, scarlet fever, mumps, measles, and whooping-cough, physicians have assumed the existence of some undiscovered micro-organisms, and have required isolation of patients, quarantining of exposed persons, and disinfection of rooms and of all articles on which bacteria from patients might have lodged.

244. How Bacteria cause Disease. — We may use diphtheria as an illustration of how bacteria cause disease. We all know that the events connected with this dreaded disease are as follows: A child is "exposed" to diphtheria, perhaps in school where other pupils have shown signs of the disease, and after a number of days the symptoms of the disease may appear. Examination of the throat discloses certain peculiar spots, and microscopic examination of material from the surface of these spots shows thousands of bacteria of the diphtheritic species. The reason why the disease did not appear immediately after exposure is that

it required time for the one or few bacteria which first lodged in the throat to multiply and form a colony.

Toxins. — The symptoms of diphtheria are not simply those of a sore throat, for the patient is evidently affected in many other organs. This seems surprising, for the bacteria are not so widely distributed; but the explanation has been found in the fact that the colony of bacteria excrete a poison (*toxin*) which is absorbed by the blood and then distributed widely in the body. Thus bacteria growing in one organ (local infection) may profoundly affect other organs in the body.

245. Antitoxins. — If the vitality of the patient is strong enough to endure the diphtheria toxin for some days, the climax of the disease is passed and convalescence ensues. The explanation of this conquering of the disease is that the cells of the patient's body have gradually secreted a substance which counteracts the toxin; this is an *antitoxin.* Those patients whose bodies are not able to secrete enough antitoxin succumb to the disease.

Every one who reads newspapers must have learned that doctors now treat diphtheria with an antitoxin obtained from horses. The explanation is as follows. A great many children are not strong enough to make in their tissues antitoxin sufficient to overcome the poisons of the diphtheria bacteria; and it cannot be known at the beginning of the disease whether the patient is going to be strong enough. Hence, it is desirable to give some artificial aid. No drug has been found to do this. But taking advantage of the fact that diphtheria toxins will cause the horse tissues to form antitoxin, which appears in the blood, physicians now inject into the blood of the human patient some antitoxin from horse blood, and this saves the child from being seriously ill while his own cells develop antitoxin. Thus it is possible to

put into the blood of a child on the first days of diphtheria more antitoxin than the child might develop in his own cells after days of illness.

Some health laboratories keep inoculated horses constantly, so as to have a supply of antitoxin ready for use by doctors who discover cases of diphtheria. The toxin injected into the horses does not make them appear sick. The withdrawing of comparatively small quantities of blood for extracting the antitoxin is done by an instrument which does no serious injury; and more antitoxin may be obtained from the same horse every month.

246. Other Diseases are Similar. — This story of the relation of bacteria to diphtheria is very similar to that of many other diseases now known to be caused by bacteria. The bacteria enter the body, multiply and form toxins. Then antitoxins or other opposing substances appear, counteract the toxins, and the patient recovers. In only a few cases has it been possible to find in other animals antitoxins which can be injected into the human tissues to cure or prevent human diseases.

Antitoxins and other antibacterial substances are specific. For example, diphtheria antitoxin will not cure or prevent any other disease, and the antitoxin which surgeons use after injuries by Fourth-of-July pistols is obtained from animals into whose bodies the toxins of tetanus or lockjaw bacteria have been injected, causing the animal's tissues to make tetanus antitoxin.

247. Immunity. — One of the most interesting things connected with bacterial diseases is the fact that some people never have certain diseases even when often exposed to infection; and also it is a rule that one is not likely to have the same diseases a second time. Furthermore, adults are not likely to have the diseases which commonly affect children.

This lack of susceptibility to diseases is known as *immunity.* Immunity which is present in human or animal individuals who are not susceptible to a certain disease is known as *natural* immunity, while that which follows an attack of a disease is said to be *acquired.*

Natural immunity is much more common than is susceptibility to germ diseases. Probably the bacteria cause disease only in a small percentage of the individuals which they enter. It is known that germs of pneumonia and other diseases are often present in persons who show no signs of disease. The reason why we do not develop disease every time a pathogenic organism enters our bodies is due to (*a*) destruction of bacteria by the white cells of the blood and lymph, (*b*) killing of bacteria by opposing soluble substances in the blood, (*c*) prevention of growth of bacteria by antiseptic conditions in the body, and (*d*) counteracting of toxins of the bacteria by antitoxins secreted by the cells of our bodies. The relative value of these four methods of protection varies with health and with individuals. In general, all four are most efficient when there is good health, and hence hygienic living by improving general health helps the human body in opposing pathogenic organisms. This is well illustrated in the case of tuberculosis, for the important factor in its prevention and cure is building up the general health.

Vaccination is an example of *acquired immunity* produced without an attack of smallpox, but by substitution of a similar and harmless disease known as cow-pox. In fact, cow-pox seems to be smallpox which has been weakened by developing in cows; and so when vaccine matter is taken from the pustules on cows and rubbed into a cut or scratch on the human skin, the result is a mild development of cow-pox. This causes the human tissues to produce some opposing

substance which effectually prevents the disease smallpox for many years, the length of immunity varying with individuals.

No scientific man questions that vaccination against smallpox has been one of the means (isolation and disinfection are others) which has made smallpox one of the rarest diseases; and that it should be practiced whenever, in a particular locality, there are cases which may have spread infection widely. For example, when a case appears in a school, all teachers and pupils in that school should be immediately protected by vaccination performed by competent doctors.

Protective Inoculation. — Similar to vaccination is protectively inoculating by giving weakened doses of toxins. Pasteur discovered that if the bacteria of cattle anthrax, or those of chicken cholera, be grown in pure cultures in test-tubes, the toxins get weaker as the cultures grow older. In other ways, also, it is possible to weaken toxins of bacteria. Now, if weakened toxins are injected first, there is a mild attack of the disease. Then a stronger toxin will produce no more effect; and using in succession in a series of days or weeks, stronger and stronger toxins, the animal into which they are injected finally becomes unable to take the disease and is said to be protectively inoculated. Many recent experiments on thousands of soldiers seem to prove that it will be possible to inoculate against typhoid in a similar way. The destructive cholera of pigs and the distemper which annually kills thousands of dogs are being studied in an attempt to find a successful way of protectively inoculating.

Hydrophobia. — The treatment for this disease is another well-known example of protective inoculation. Persons bitten by dogs believed to have rabies go to a Pasteur Institute, and receive frequent injections of weakened toxins

obtained from the spinal cords of rabbits which have died with the disease. The result of these weakened doses, which are increased in strength with each successive injection, is that the person treated acquires immunity; that is, he probably develops an antitoxin faster than the toxins introduced by the saliva of the rabid dog can act. At present, no other method of dealing with this terrible disease is known, and hence it is important that protective inoculation be applied as soon as possible. But much common sense is needed in dealing with dog bites. There is no foundation for the idea that dogs are liable to go "mad" in "dog days." *Most dogs* which bite or appear sick *are not rabid.* Hydrophobia is *a rare disease.* One who is bitten by a dog should have the wound properly treated by a surgeon, for blood-poisoning bacteria may get into any deep wound. If the dog shows signs of illness, it should be kept in confinement for some days; for if it is rabid, the disease will develop rapidly. If the dog has been killed, its body should be expressed, packed in ice, to the nearest Pasteur Institute or health laboratory. Microscopic examination of the nervous organs will show whether the dog had hydrophobia, and it can be quickly determined whether protective inoculation should be given to the person who was bitten.

248. Few Bacteria cause Disease. — The student should not infer from the preceding description that all species of bacteria affect human health. The fact is that most species now known are not pathogenic (disease producing). Certain species actually protect our health because they decompose organic matter, such as sewage, which may contain dangerous typhoid or other bacteria. These and other useful bacteria will be described in § 271.

Bacteriology Applied to Human Health

249. Bacteriology and Health. — The principles of bacteriology which have been discovered within the past thirty years are not only of interest in connection with the cause and cure of many diseases, but are also of much greater importance in that they are capable of being applied so as to maintain health. The relation of bacteriology to hygiene is a vast subject, and we can take time only for a few of the most important points. We shall consider (1) how to avoid the disease germs which are widespread, and (2) how to prevent the wide distribution of disease germs.

250. Avoiding Disease Germs. — The methods of avoiding the introduction of disease germs into one's body depend upon the nature of the disease and the causative organism. As a rule, the germs are introduced into the alimentary canal with food and water, into the respiratory organs, into the blood by insect bites, or into wounds.

251. Infection through Alimentary Canal. — Typhoid fever and Asiatic cholera are good examples of intestinal diseases caused by germs which are spread by excreta. Imperfect sewerage and insects may lead to contamination of various foods (milk, vegetables, fruits, raw oysters) and drinking water. In places where these diseases are common the only safety for the individual is in the use of cooked foods, which should be served hot or at least guarded from contamination by flies, dirty hands, and dust. Salads and other vegetables not cooked should *at least* be carefully washed in water which has been boiled.

If there is reason to doubt the purity of drinking water, heat it to the boiling temperature and pour into sterile closed containers (such as earthen jugs). Longer boiling is unnecessary and undesirable. These rules will protect

individuals. How to check the spread of intestinal diseases and thus protect the public is a problem of sewerage, and of insect control (see § 261).

Intestinal diseases of children, especially in warm weather ("summer complaint"), are largely due to stale milk. If very clean, fresh milk is not available, then the milk should be pasteurized (§ 239). Thoroughly wash and sterilize all milk-bottles daily.

It should be remembered that some bacteria of decay may develop in foods and cause unhealthful conditions. This and the fact that some disease germs will multiply in milk and other foods should lead to caution. Foods showing signs of decomposition should, of course, be rejected; but more important is the protection of foods from dust, insects, and growth of bacteria. Remembering that bacteria do not flourish when very cold, one thinks of the ice-box as best for preventing growth; but rarely is an ice-box cold enough to preserve highly decomposable foods (such as soup, gelatin, milk) for many days. Best of all methods is to heat to the boiling point daily the foods to be preserved temporarily, and also to keep them in an ice-box from day to day. Thus disease germs, if present, will be killed; and ordinary decay, which might produce ptomaines (poisons in foods), is prevented.

252. Infection through Respiratory Organs. — Tuberculosis is a good example. Tubercle bacilli may get into the lungs (1) by close contact of healthy with tuberculous persons (*e.g.*, by kissing, and by using drinking cups or towels in common); (2) from dust arising from the dried sputum of a tuberculous victim; (3) possibly from milk of tuberculous cows; (4) by flies which carry the bacteria from sputum. The first line of danger is easily avoided. Especially should those who suffer from tuberculosis or whose friends are afflicted

apply to the Society for the Prevention of Tuberculosis, in New York City, for free circulars and follow carefully the rules which they give for preventing the spread of the disease. Doubtful milk should always be pasteurized, or boiled. The danger from dust is impossible of avoidance by individuals so long as the spitting nuisance continues. Fortunately drying and sunlight kill most of the germs out of doors, and good ventilation and cleaning reduce the danger indoors.

So far as personal hygiene is concerned, the most important preventive measure against pulmonary tuberculosis is keeping in general good health by good food, outdoor exercise, fresh air, good sleep, and avoiding colds. So long as the body is in good condition there is little danger of the bacteria getting a chance to flourish in the lungs; and even if the disease has begun to develop, a cure may be effected by careful attention to the rules of hygiene which physicians and special books and pamphlets prescribe.

Many *children's diseases* (whooping cough, measles, mumps, chicken-pox, etc.) are believed to be contracted through the respiratory organs. The best protection is (1) keeping away from cases of such diseases, and (2) avoiding the use of pencils, toys, towels, handkerchiefs, drinking cups, etc., which may have been in contact with the mouths of other children, who may carry the germs although apparently well. These and the biological rules given in § 255 will prevent most epidemics of children's diseases.

253. Infection by Insects. — The relation of mosquitoes and flies to disease is stated in §§ 260, 261. Constant warfare should be waged against these insects.

254. Infection in Wounds. — Proper healing without inflammation depends upon keeping out bacteria. Wash all cuts with weak antiseptics obtained from druggists (*e.g.*,

carbolic acid one part to 40 of water, or mercuric chloride tablets in water as directed on bottle. Listerine or strong alcohol for slight cuts). Deep cuts or punctures should be dressed by a surgeon, for bacteria may have been pushed in too deep to be reached without special instruments, and there is danger of tetanus (lockjaw) or septicæmia (blood poisoning). Protect wounds with sterilized cotton and medicated gauze. Adhesive tape should not be put on so closely as to keep out the air; and collodion solution is of questionable value for any except shallow and well-cleaned cuts. Always consult a doctor at once if any marked inflammation develops in any wound. Delay in such cases often proves serious.

255. Preventing Distribution of Disease Germs. — This may be accomplished (1) by scientifically dealing with cases of germ diseases, which we discuss below under "the bacteriology of sick-rooms"; and (2) by public sanitary control of food-supplies, water, sewage, quarantines, and other matters of public hygiene.

256. Bacteriology of Sick-Rooms. — Since it often happens, especially with children, that germ diseases must be treated at home, it is important that every citizen should understand the scientific principles which doctors prescribe. All the rules depend upon the fact that micro-organisms are numerous in the secretions and excretions of patients, and must be destroyed by the methods of bacteriology.

(1) *Isolation.* — As soon as a person becomes ill, he should remain in one room until the doctor is sure of the diagnosis. If it proves to be a contagious disease, complete isolation will be required by the health officers. Even in cases of diseases not commonly isolated it is best that only the nurse come into contact with the patient, for there is always possible danger of spreading the germs to healthy people. In the cases of all dangerous diseases, the doorway to the

patient's room should be kept covered with a damp sheet to prevent as far as possible the exit of dust particles.

(2) *Disinfection.* — Remember that all articles in contact with a patient may bear the germs. To reduce the amount of disinfection which will be necessary, remove all useless carpets, curtains, and furniture as soon as the disease is diagnosed; and thereafter remove nothing from the room except under the strictest germicidal precautions. Hence all clothing, bedding, handkerchiefs, etc., should be placed in a tight receptacle, such as a wash-boiler, covered with water, and boiled for twenty minutes before they can safely be sent to a laundry or washed in tubs at home. The wash-boiler should be kept in the patient's room, and not opened until after boiling. Its outside should be wiped with a cloth wet with strong washing-powder solution, or other germicide, if necessary to take it to another room for boiling.

Spoons, dishes, tumblers, etc., should be placed in a bucket of water (preferably hot and containing much washing-powder) before removing from the patient's room, and then boiled for 20 to 30 minutes. Food left by the patient should also be boiled or burned. Playthings used by children should be such as can be washed in germicide solutions, boiled, or burned after convalescence. A doll or a "teddy bear," if not burned, might be a very dangerous carrier of germs. It is best to give the patient books or magazines of little value, never those from libraries, and finally carry them (in a closed bucket) to a stove or furnace.

The one who attends the patient should thoroughly wash her hands frequently with hot water and soap, or with germicide solutions, before leaving the room. Neglect of this simple precaution has often spread germ diseases. The habit of expert nurses of wearing washable dresses should be imitated as far as possible.

All excreta should be treated with strong chloride of lime or other cheap disinfectants sold by druggists. Proprietary disinfectants are expensive and rarely reliable.

No sweeping should be allowed in a sick-room. Dust should be wiped up with a damp cloth which should afterward be cleaned in boiling water with washing-powder.

After recovery of the patient, fumigate (disinfect by fumes or gas) the room with formaldehyde (§ 239, *f*), leaving in the room all furniture, pictures, mattresses, books, etc., and opening the drawers, wardrobe, etc., so as to allow free circulation of the gas. Do not remove rugs, curtains, clothing, or any article from the room until after thorough disinfection.

These precautions may seem extremely detailed, but bacteriologists have shown that they are necessary in order to safeguard against distribution of dangerous germs. It is the duty of every citizen to aid in popularizing and putting into practice this knowledge by which some of the most dangerous diseases may be made extremely rare in occurrence.

257. Public Hygiene. — Since a large number of people are ignorant of scientific principles or have no regard for the health of other people, it has become necessary to institute public sanitary control of foods, water, sewage, quarantines, etc., in all cities and to a certain extent in the country at large. Thus the official representatives of the government are charged with the duty of protecting citizens against disease in cases where the individuals cannot exert control. For example, a city board of health can force dealers to sell only clean milk, but without such public control the individual citizen must accept the impure milk which the dealer offers for sale. Likewise, under public sanitary control, meats and other foods can be inspected and made to meet the requirements of the law; water can be obtained from

the purest possible sources; sewage systems can be arranged to avoid danger from disease germs; streets and other public places kept clean; quarantine of dangerous diseases established; vaccination required; spitting on walks prohibited; and still other measures in the interest of public health put into legal operation. Such is the field of public hygiene and the work of health officials, who aim to apply biological principles and protect the citizens in numerous cases where individuals cannot protect themselves. Every citizen should get acquainted with the health laws in his locality and then coöperate with the officials whose duty it is to get the laws enforced.

II. ANIMALS THAT AFFECT HEALTH

We shall consider first some of the simplest animals (Protozoa) which cause diseases similar to those of bacterial origin. Most important of these are the microscopic animal parasites that cause malaria.

258. Malarial Organism. — Malaria in its severest forms has long been one of the worst diseases affecting the human race. Vast territories in some parts of the world have been left practically undeveloped by civilized men because of malaria. Little was known as to the cause of the disease until after 1880, in which year a protozoan parasite was discovered in red blood-cells. Before that time malaria was commonly supposed to be caused by some poisonous vapor or miasm which arose from swampy land. In fact, the very word "malaria" means bad air. In 1897, Ross, an officer of the British army, demonstrated that the malarial parasites develop in the stomachs of certain mosquitoes (§ 260) which have sucked blood from persons who have malaria; and a year later other investigators showed that mosquitoes which have obtained blood from a malarious

patient are able to transmit the parasites while sucking blood from perfectly healthy persons. Many later studies have made it absolutely certain that the Anopheles mosquito is the carrier of the disease; and this is one reason for the recent attempts at exterminating mosquitoes as far as possible (§ 260).

The effect of the malarial parasite upon the red blood-corpuscles is as follows: Small bodies injected into human blood by sucking mosquitoes attach themselves to blood-cells and begin to burrow (they have amœboid, amœba-like, movements). Soon there are formed in the blood-cell (§§ 6–24) small bodies called *spores*. Then the blood-cell disintegrates and frees the spores, which fasten themselves to new blood-cells and repeat the development. Each time the spores are freed by breaking of the blood-cells, the patient has the chill and fever which are characteristic of the disease. It is well known that malarial attacks commonly occur on alternate days, that is, every forty-eight hours. This means that a common form of malarial parasite requires two days for development in blood-cells. Another variety of malarial parasite takes three days for development into spores, and so the chill of the patient comes at intervals of three days.

All these oft-repeated cycles of development in human blood-cells are simply growth and cell-division, typical asexual reproduction. When human blood from a malarious patient is sucked into the stomach of a mosquito, pairs of certain spores unite (a true case of fertilization) and the zygote (combined cell) penetrates the stomach-wall of the mosquito and becomes encysted. Sometimes there are several hundred such cysts in the stomach of a single mosquito. Each of these encysted parasites eventually divides into thousands of slender thread-like bodies (sporozoites), which by way of the lymph-tubes get scattered in all parts

of the mosquito's body, especially in the poison (salivary) glands. It is these sporozoites which are carried along with the poison when a mosquito plunges its beak into human blood-vessels; and each sporozoite enters a red blood-cell, where it divides into 6 to 24 spores.

The full development in a mosquito's body need not take over ten days in warm weather.

When once started in human blood the repeated cycles may go on for a long time, or spores remain which may long afterward start a new attack of the disease. This can be prevented by the use of quinine, which kills the parasites, especially if taken when the fever is subsiding, which is while the young spores are free in the blood-plasma. Killing the parasites in human blood prevents infection of mosquitoes; and if all infected people could be treated with quinine systematically, it is probable that the disease could be stamped out. Preventing the spread of the malarial parasite by preventing the breeding of mosquitoes and by protection against bites will be discussed in § 260.

259. Other Protozoan Diseases. — The terrible South African disease known as the sleeping sickness, from which more than half a million natives in the Congo region have perished in the last ten years, is now known to be due to a parasitic protozoan which is injected into human blood-plasma by the bite of a peculiar African fly. The parasite swims freely in blood-plasma. Many experts on parasitic diseases are now engaged in studying the sleeping sickness; but so far no satisfactory remedy has been discovered. It is spreading rapidly, and has become one of the greatest problems in Africa.

There are some suggestions that yellow fever, scarlet fever, smallpox, and hydrophobia are caused by protozoan parasites similar to those which cause malaria; but there is yet no

convincing proof. In the case of yellow fever, it has been proved that a mosquito (not the species concerned with malaria) transmits the unknown germ of the disease; and so at present the only known way of checking the spread of yellow fever is to check the mosquitoes. This has been very successful in Cuba and in Panama.

Fortunately, most of the protozoans which live in lakes, rivers, and seas are unable to live in the bodies of animals and humans, and hence are entirely harmless.

260. Mosquitoes and Diseases. — Careful investigations made in recent years have proved that certain insects are responsible for transmission of disease germs. The most famous case is that of mosquitoes of the genus Anopheles (Fig. 72), which inject the malarial organism (§ 258) into the human blood-system. Numerous experiments have made it certain that this mosquito is harmless unless it sucks blood from a person who has malarial parasites, and it is now certain that a bite from such an infected mosquito is the only way by which malaria can be acquired.

It is also quite certain that another species of mosquito is responsible for transmission of yellow fever, the germ of which is still unknown.

The discovery that mosquitoes are thus connected with certain dreaded diseases has led to a study of the life-histories and habits of these insects, with a view to reducing the number of cases of malaria and yellow fever. The following rules are now agreed upon by competent entomologists.

(1) Multiplication of mosquitoes should be checked by destroying their breeding places; for example, by draining swamps, ponds, and other places containing stagnant water. Even a rain-water barrel, open cistern or tank, buckets, empty fruit-cans, cavities in trees and stones, — in short,

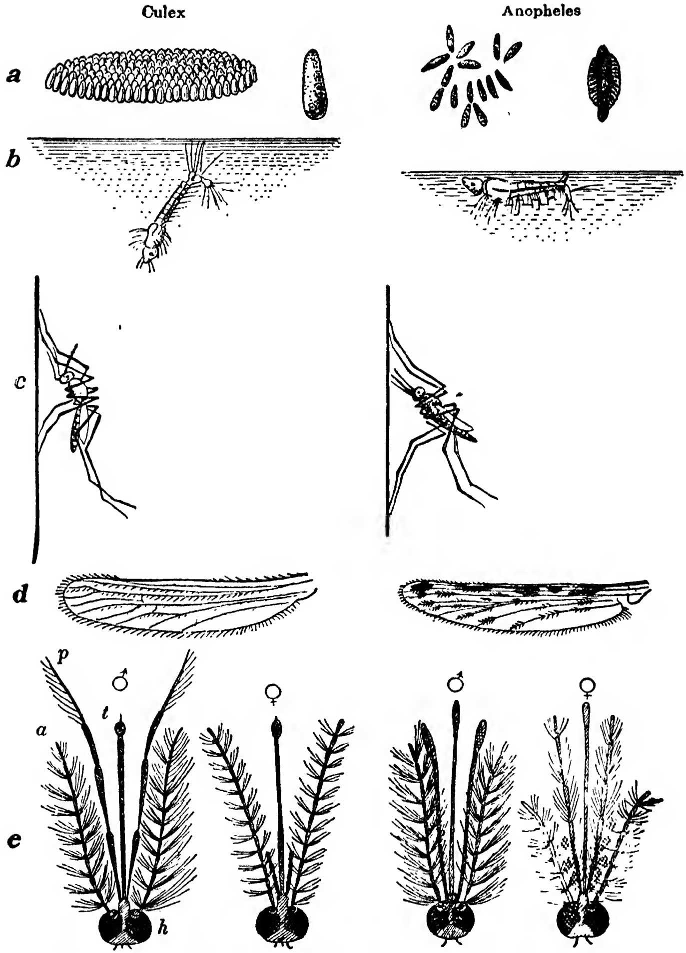

FIG. 72. Comparison of malarial mosquito and common culex. *a*, eggs; *b*, position of larvæ at surface of water; *c*, position of resting adults; *d*, wings; *e*, head appendages — *a*, antenna; *p*, palp; *t*, tongue. Compare lengths of palps of the females. (*From Jordan's "Bacteriology," after other authors.*)

any place where a small quantity of water stands for a few days may serve as a breeding place, producing thousands of mosquitoes. As far as possible all such places should be arranged for permanent drainage, and others, such as cisterns and barrels, should be tightly covered or screened with netting so as to exclude mosquitoes which are about to lay eggs.

(2) Mosquitoes should be destroyed in the larval stages when it is impracticable to follow the rule above. Many streams, lakes, etc., cannot be drained; but stocking them with fishes will result in destruction of most of the mosquito larvæ. It is important in such cases that the banks of the streams be freed from rubbish and graded so that there will be no small depressions in which mosquitoes may lay their eggs safe from the attacks of fishes.

Oftentimes temporary relief, pending permanent drainage, may be gained by spraying crude petroleum on the surface of stagnant ponds. This will destroy the larvæ when they come to the surface to breathe. Oil cannot be used if it is desired to preserve plants and fishes in the water.

(3) People should guard against infection by avoiding mosquito bites, especially when in a region where malaria is known to occur each year, or when there is an epidemic of yellow fever in the southern states. The methods of avoiding bites are very simple. Houses should be well screened, and isolated mosquitoes resting on the walls and ceilings of bed-rooms should be killed each evening. Persons obliged to be outdoors at night should wear thick and loose clothing, and mosquito-proof veiling around the head.

(4) Persons suffering from malaria should remember that their duty to their fellowmen demands that every possible precaution be taken against being bitten by mosquitoes. A drop of blood from a malarious patient may infect a mos-

quito so that later it may inject the malarial organisms into healthy people. In cases of yellow fever it is now the rule to quarantine the patient in a screened room, and then make sure that no infected mosquitoes escape. This can be done by closing the room tightly after removal of the patient and burning sulphur, which will kill any mosquitoes concealed in the room.

Especially should the above precautions be taken against malaria when Anopheles mosquitoes are common. Hence, it is important that this species be easily identified. (See Fig. 72.)

261. Flies and Disease. — Probably more important than mosquitoes as carriers of disease germs are the common house-flies. It is a well-known fact that these flies persist in walking on food, and long before disease germs were known, careful housewives made strenuous efforts at keeping them from kitchens and dining-rooms. Recent bacteriological studies have disclosed some startling facts which should lead to a general declaration of war against the house-flies. The facts are these: A fly allowed to walk across a sterile gelatin plate will leave in its tracks many bacteria previously acquired by walking on filth. Now, if a fly walks on sewage containing germs of typhoid or of other intestinal diseases, or on sputum from a tuberculous patient, and later walks on food or on dishes ready to be used for food or drinking water, it may leave in its tracks dangerous bacteria, which may be taken into the body with the food or water, and then cause disease. It is obvious that in this way a single house-fly may be a very dangerous animal.

It has recently been discovered that the biting stable-fly may transmit the germs of infantile paralysis.

There are several ways of combating this dangerous pest: (1) Manure piles and similar breeding-places should be re-

moved. (2) Houses should be carefully screened and fly-poisons, traps, etc., used to kill the few that succeed in entering. (3) All foods should be carefully guarded against flies. (4) Arrangements for sewage disposal should be such that flies cannot distribute bacteria. For this reason sewers and cesspools that discharge into porous drain-tiles below the surface of soil are preferable for country and village homes.

262. Other Insects and Disease. — Mosquitoes and house-flies are the most important insects connected with diseases in America, but other insects may likewise affect human health. The germ of the terrible African sleeping sickness is injected into the blood by the bite of a peculiar fly. The bacteria of bubonic plague is probably transmitted by fleas which infest rats in whose blood the germs occur. In fact, any biting insect which gets an opportunity to bite any person or animal whose blood contains disease germs may become a carrier of the germs; and any insect which comes in contact with germs and later with human food may indirectly cause disease.

The above account suggests the general relations of certain insects to human diseases. For more facts on this very important subject read the pamphlets on "Mosquitoes" and "Insects and Health" published by the United States Department of Agriculture.

263. Tape-worms. — All the worms known as tape-worms are parasites in the alimentary canal of vertebrate animals and humans. They have no mouth or digestive organs, but absorb through their skin the digested food in the alimentary canal of the host in which they live.

A tape-worm's body resembles a long, narrow ribbon or tape, but is unlike a ribbon in that it is divided into segments (Fig. 73, *c*), and is narrow near the anterior end. The

head is a rounded knob, with a circle of hooks and four suckers by means of which the worm holds fast to the lining of the intestine. There are nerves and excretory tubes in each segment. Each of the larger segments towards the posterior end has a complete hermaphroditic reproductive system, consisting of ovaries, spermaries, and their ducts leading to the surface. The extreme posterior segments become greatly distended with enormous quantities of fertilized eggs, each inclosed in a hard shell; and one by one these "ripe" segments drop off and are carried out of the intestine with indigestible matters or feces. As segments drop off the worm, new ones are formed by new grooves in the segments back of the head. Thus the oldest segments are the most posterior ones.

At the time a "ripe" segment is discharged from the intestine, each egg-shell contains a small embryo with six hooks. If these small embryos, in the case of the human tapeworms, happen to fall on grass or other food of pigs and cattle, the digestive

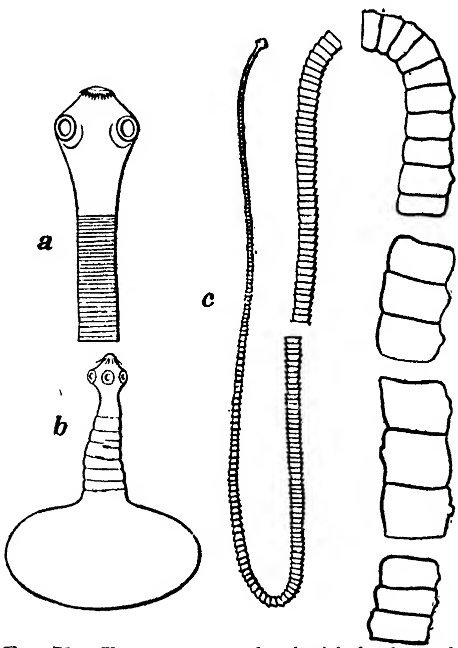

FIG. 73. Tape-worm. *a*, head with hooks and suckers; *b*, bladder-worm stage; *c*, parts of an adult worm, oldest segments are largest.

fluids in the stomachs of these animals dissolve the hard shell and free the embryo. Then it bores into some organ of its host, becomes encysted, and develops a larva which is bladder-like with a tape-worm head (Fig. 73, *b*). This stage (called a bladder-worm or cysticercus) in the tissues is dangerous; for if uncooked pork or beef be eaten by man, an encysted bladder-worm may attach itself to the wall of the human intestine by means of its hooks and suckers and develop into a tape-worm.

The above account of the human tape-worms, of which one species develops its bladder-worm stage in pigs and another in cattle, represents the life-history of all the tape-worms which inhabit the intestines of various vertebrates. Two hosts are required, one for the tape-worm, and one for the intermediate bladder-worm stage. One species of tape-worm of dogs has its bladder-worm in rabbits; one of sea-gulls has its in earth-worms; and one of cats has its in liver of rats and mice. In Oriental countries there is a large human tape-worm whose bladder-worm stage is passed in certain fishes. The bladder-worm stage commonly occurs in the particular animal which is a favorite food of the host of the fully developed worm.

Tape-worms are troublesome parasites in that they interfere with the nutrition of the animals which they inhabit. They are difficult to remove, because the head is so firmly attached to the lining of the intestine. All the segments might be dislodged by powerful drugs, but if the head remained, it might continue to grow new segments.

Preventing infection of humans by the larvæ of tape-worms is a simple matter; namely, eat no meat raw or "cooked very rare." In the case of pork there is an additional reason for this rule, in that the far more dangerous parasite Trichina (§ 264) may be present. With increasing

attention to sanitation and disposal of sewage by bacterial methods, there will be less chance of tape-worm embryos getting into pigs and cattle and then indirectly entering human beings. The rarity of human tape-worms in United States is probably in part due to the fact that our farms are more sanitary, and being larger than those of Europe, farm animals live farther away from human dwellings.

264. Round Worms. — A good example of a *harmless* round worm is the vinegar-eel, which is often abundant in unfiltered vinegar, and especially in "mother-of-vinegar." They should be examined with the low power of a microscope.

Many species of the round worms are parasitic in intestines of man and animals. Some are slender threads half an inch long, while others may be a foot long.

The most terrible round worm is the trichina. The adult worms live in the intestine of man, pig, and other mammals. The males are about 1 mm. ($\frac{1}{25}$ inch) and the females 3 mm. long. The eggs develop inside the female, and the young (1000 or more) are born alive; that is, discharged as young worms. These pass through the walls of the intestine of their host, and reach such muscles as those of the arms, legs, and back. Each worm embeds itself in a muscle-fiber (Fig. 74), and a cyst forms around it. It may remain encysted for years. An ounce of infected pork may have 80,000 such cysts. If the flesh be eaten by another animal or by man, the cysts dissolve in the digestive organs, the young worms develop, form eggs and sperms, and fertilized eggs develop into young worms which become encysted in muscles. In a town in Germany, in 1884, the flesh of one pig infected 364

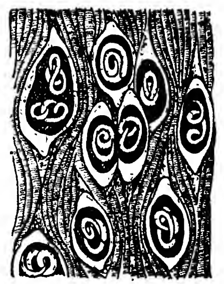

FIG. 74. Trichinæ encysted in muscle. (*After Leuckart.*)

persons, and 57 died within a month. This large number of infections is easily understood when we calculate from the figures above. A single ounce of pork might introduce into a human stomach 80,000 trichinæ. Suppose one half of these are females, each able to produce 1000 young worms, and four million encysted worms might be the result. Thus, at this rate, 100 pounds of pork might contain enough cysts to develop 64 billions of encysted worms, or 160 million for each of 400 persons who might eat the pork. And this is not the whole story, for a female trichina may live in the human intestine and frequently give birth to as many as 1000 young.

There is no way to destroy the worms when once they get into the human intestine. If the infected individual does not soon die from the inflammation caused by the encysting in the muscles, the cysts soon become hardened and there is no more danger to the patient. Prevention is very simple; namely, eat no pork which is not well cooked. In some countries, government inspectors examine meats at the great slaughter houses, and condemn as unfit for human food all meat found to have trichinæ. If the parasites are present in a pig, they are likely to be so abundant that a small piece of lean meat (muscle) examined with a microscope will reveal the trichinæ. However, such inspection is not infallible, for the parasites have been sometimes overlooked by expert inspectors.

The above account has not explained how pigs get infected. Since they do not eat human flesh, they must get the parasites from some other animal. Trichinæ are found in rats, and it is well known that pigs will eat dead rats. Also, pigs eat scraps of pig meat such as are thrown away by butchers on farms.

265. Poisonous Arthropods. — The important groups of

arthropods are the crustaceans (crabs, lobsters, shrimps), the arachnids (spiders, scorpions, mites, ticks), the myriopods (centipedes), and the insects. The crustaceans are all harmless, except that some of the large forms may produce painful wounds by their pincer-like claws. The scorpions, found in warm countries, have a sting at the end of the "tail," which is really a part of the abdomen. Some large ones, six to eight inches long, can seriously poison man, and the sting of even the small ones is painful. The poison-glands of spiders secrete a fluid which is injected through the hollow biting jaws and may kill small animals; but is not fatal to larger animals or man. Possibly people with weak hearts have died from fright, but not from the direct effects of the poison. The harvestmen or daddy-long-legs resemble long-legged spiders, and are popularly, but wrongly, supposed to be poisonous to humans. Centipedes have poison-glands whose secretion is conducted to the hooked ends of the first pair of feet. The large tropical species may kill small animals and cause great pain to humans; but the common ones of temperate climates cause no more pain than does a mosquito bite. Among the insects there are many able to produce painful injuries to human skin. The females of the bees and wasps have stings at the end of the abdomen. The hair-like spines on certain caterpillars carry a very irritating fluid. The bite of the female black flies sometimes produces painful inflammation. Mosquito bites are sometimes said to cause blood poisoning, but this results from the introduction of bacteria, not from the irritating saliva of the

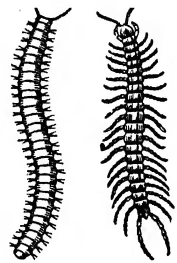

FIG. 75. Two kinds of myriopods. *A*, milliped; *B*, centipede. *(From Thomson.)*

insect. A blistering fluid is secreted by the blister-beetles, which are known in pharmacy as "Spanish flies" or cantharides. The poison from a single insect cannot kill a human with good heart action, but the combined effect of many stings is certainly dangerous. Many insects are traditionally credited with being harmful in peculiar ways, such as earwigs that were once supposed to enter people's ears during sleep, dragon-flies that were said to use their long "tails" (abdomens) as darning-needles to pierce children's ears, and many other such stories equally absurd in these days when science has given us an understanding of the structure and life of insects.

266. Dangerous Vertebrates. — Among the fishes, the sting-rays have caudal spines without poison, while the fin spines of toad-fishes and certain cat-fishes have poison-glands. Wounds from any of these are very painful and may be fatal if blood-poisoning bacteria happen to be introduced. The electric-rays or torpedoes, the electric-eel of Paraguay, and the electric cat-fish of the Nile have electric organs able to give severe shocks when the fishes are touched. The flesh of most fishes contains no poisonous substances when fresh. Ptomaine poisoning from fish meat is caused by decomposition by bacteria and the poisons are the same as might develop in any other spoiled meat. A few tropical species of fishes are said to have poisonous flesh.

None of the amphibians (frogs, toads, and salamanders) is dangerous; and even the supposed production of warts by toad secretion is zoölogical myth.

Poisonous snakes belong to many different families. The American moccasins, rattlesnakes, and copperheads, and the Old World cobra, adders, and vipers are the most poisonous reptiles. Official figures show that in India alone more than 20,000 people die annually from snake bites, but there

are few fatal cases in the United States. Pythons, boas, and anacondas are snakes which kill animals by constricting, but it is doubtful whether they have killed men and large mammals. Most of the snakes of the United States are not poisonous. Snake poisons are secreted by glands in the upper lips, and the "poison fangs" are upper teeth with grooves or tubes for conveying poison beneath the skin of the victims.

The remedies for snake bites are briefly as follows: —

(1) Place tight ligature on arm or leg to prevent circulation of blood; (2) cut and enlarge the punctures made by fangs in order to drain away as much poisoned blood as possible; (3) wash out cuts with wine-colored solution of potassium permanganate; (4) take *very small* doses of alcoholic stimulants, enough to cause increased pulse-beats; larger doses are dangerous; (5) consult a good surgeon as soon as possible, because blood poisoning may result from the wound, and also it may be necessary to have stimulants and anti-venomous serum injected hypodermically; (6) keep the wound covered with a cloth or cotton wet with some antiseptic solution.

No bird or mammal has poison-glands, and the flesh of all of them is edible if one considers the absence of poison rather than palatability. It is true that bites and scratches from the beaks, jaws, and feet of birds and mammals have been known to cause blood poisoning and tetanus, but introduced bacteria are known to produce the poisons. Mammals, such as dogs and wolves, often cause hydrophobia (§ 247) by their bites, probably by transferring an unknown micro-organism that produces a poison or toxin.

267. Summary of Organisms Affecting Health. — This chapter has given a brief account of some of the most important organisms that are known to affect human health.

Many of these are rapidly coming under control of man. With modern firearms we no longer fear the large and dangerous mammals. We know how to dress wounds so as to prevent the growth of blood-poisoning bacteria which various animals may introduce with their bites and stings. The poisonous snakes rarely injure those who take proper precautions (such as wearing strong boots, which the natives of India do not do for protection against the deadly cobra). Many insects which carry the germs of disease are now recognized, and we are learning how to destroy them or to prevent their bites. The chief poisonous plants which we must avoid eating or touching are well known. Science has made wonderful progress in fifty years against the micro-organisms that cause some of the most dangerous diseases. A large part of the highly efficient science of public hygiene or sanitation is concerned with preventing the distribution of the dangerous micro-organisms; and the science of medicine is making rapid progress in preventing and curing some of the germ diseases. In short, the world is a vastly safer place than it was one hundred years ago, because biological science has so extensively investigated the organisms that affect human health.

CHAPTER XI

THE ECONOMIC RELATIONS OF ORGANISMS

268. Many plants and animals are of interest to us in economic ways; that is, they are either useful or harmful. For example, horses and cows and corn are of economic importance because we make use of them, while some insects are of economic importance because they destroy useful plants that have a pecuniary value. Some of the most important of the economic relations of animals and plants are those of cultivated plants and domesticated animals, and hence of very direct interest to farmers. The economic relations of these useful animals and plants grown on farms also concern those of us who happen to be living in cities, for everybody's supply of food and clothing depends upon the industry of agriculture which supplies the necessary animal and plant materials out of which our foods and clothing are made. As an illustration, if insects destroy the wheat crop in several States, or disease kills many thousands of animals (*e.g.*, hog cholera in 1911), the price of bread and meat will rise in both country and city. Not only do the farmers lose what they could sell for much money, but every person's living expenses will be affected by the increased prices due to decreased production. Hence, we are all interested in good crops on the farms; and it is well known that our national prosperity is greatest when the farmers succeed in producing a large supply of such animals and plants as are needed especially for food and clothing. In

short, the economic problems of animals and plants are not limited in interest to those who grow them for market; and many intelligent city people are much interested in the success of the farmers, for they realize the dependence of everybody upon agriculture. In fact, if the farmers do not learn how to increase their production of foods by making the land more fertile and their management of animals more scientific, the time will come in America when there will not be grown enough animals and plants to feed liberally several hundred millions of people.

These illustrations of the relation between animals and plants and our everyday life will help the reader of the following pages to see how many of the organisms mentioned may be of economic interest to very many people. Most of the economic relations selected for study affect all of us, in both country and city. In some cases there are both hygienic and economic relations of great importance; for instance, if tuberculosis of cattle is neglected and allowed to become widespread among dairy cows, it will not only make milk unhealthful, but the ultimate destruction of the diseased cows will make it necessary for the dairyman to charge more for the milk in order to balance the financial loss from cows destroyed. In such a case both the health and the pocketbooks of all people who use milk may be affected; and hence we recognize that the bacteria which cause the tuberculosis of cattle are of economic importance to city people as well as to farmers.

Having thus considered how economic problems of biology are of importance to everybody, we may go on to study some of the most important relations of animals and plants.

I. PLANTS OF ECONOMIC IMPORTANCE

(a) *Bacteria*

269. Bacteria in Foods. — In the preceding chapter we have considered the relation of bacteria to human health so far as they are the direct causes of disease. It is possible that bacteria might indirectly cause some disease, such as disturbances of the digestive organs, because they decompose foods; and so the relation of bacteria to foods is partly a matter of hygiene and might properly have been referred to in the preceding chapter devoted to health problems. However, most foods which are noticeably decomposed by bacteria are thrown away, and hence there is economic loss rather than harm to health. Vast quantities of milk, meats, and canned goods are spoiled by bacteria before they reach the consumers; while in the average home there is much financial loss from the action of bacteria on prepared foods. This loss is in part reduced by cold storage of foods in ice-boxes; by preserving with the aid of such antiseptics as common salt, vinegar, spices, and strong sugar sirup; by sterilizing with heat; and by sealing in preserving jars so as to prevent entrance of bacteria. Ice-boxes are useful only for temporary storage, for they commonly have a temperature several degrees above freezing and certain bacteria develop. Sterilizing by heat is the most valuable of all methods for food preservation; but for the greatest success certain precautions must be observed: Boiling once does not kill spores, and hence peas, beans, sweet corn, meats, and soups must be boiled on three or four successive days, or else subjected to steam pressure of 20 to 30 pounds, in order to preserve them in cans or fruit-jars.

The reason why tomatoes, cherries, plums, and many fruits are easily preserved if boiled once and packed in

sterilized cans while hot, is that their composition is not favorable for growth of bacteria. In fact, they are most liable to fermentation by yeast plants, and these are killed by heating to boiling temperature. They also favor the growth of molds whose spores do not readily germinate in sealed cans.

270. Bacteria and Diseases of Domesticated Animals. — A very important economic aspect of bacteria is their responsibility for many destructive diseases of domesticated animals. In recent years it has been discovered that a large number of cows and pigs are infected with tuberculosis, which many bacteriologists think is the same as the human form of the disease. But even if it were not probable that the disease can be transmitted from cattle to humans, it is of interest because it is now causing enormous financial losses. The scientific agriculturists of this country are now very much alarmed and are attempting to check the disease by means of quarantining, slaughter of diseased cattle, disinfection of stables, and sterilization of milk fed to calves and pigs. Many other diseases of cattle, horses, pigs, sheep, poultry, and dogs are caused by bacteria. In general, bacterial diseases of animals are like the human infectious diseases in that they are more easily prevented than cured. Isolation of sick individuals, disinfection of living quarters, pure food, pure water, and protective inoculation or vaccination are some of the essentials in preventing the widespread distribution of destructive germs. Even with these precautions, it sometimes happens that a disease of animals becomes epidemic. As an example, several million dollars' worth of hogs have been killed within the years 1910–1912 by hog cholera, the germs of which have become widely scattered, especially in the States north of the Ohio River. At present (1912) thousands of hogs are being protectively inoculated

with the hope of rendering them immune to the cholera bacteria, which are now so abundant on many farms that for several years there will be danger of a new epidemic.

271. Useful Bacteria. — The popular impression is that all bacteria are harmful in that they decompose our foods or cause dangerous diseases of man or of useful animals. This is far from true, for very many bacteria are directly useful.

(*a*) *Bacteria in Soils.* — Most important of the useful bacteria are those which deal with the nitrogen compounds in the soil. The nitrogenous excretions of animals and the dead bodies of animals and plants must be changed by bacteria before the contained nitrogen is ready for use by plants. Moreover, certain kinds of bacteria found in the tubercles on roots of beans, clovers, and their allies are able to collect nitrogen from the air and to use it in elaborating nitrogenous plant food. For a fuller account of bacteria in soils, see "Applied Biology," § 258.

(*b*) *Bacteria in Milk.* — The most common bacteria in milk are those which produce lactic acid, which causes milk to sour and coagulate. While this process may be undesirable in milk intended for drinking, it is useful in the making of certain kinds of cheese. Moreover, the presence of the lactic bacteria in milk prevents the growth of certain species which cause putrefaction. If milk be heated to 70° C. (pasteurized), the lactic bacteria are killed and others capable of producing putrefaction remain.

(*D*) A bottle of raw milk and one of pasteurized, left covered just as delivered by the milkman, should be placed side by side, either in an ice-box or on a table in the schoolroom, and examined as to appearance and odor after two or three days. It is also interesting to add a little sour milk (*i.e.*, with lactic bacteria) to a bottle of freshly pasteurized milk, and note that the putrefactive odors are prevented while souring occurs.

There is no reason to think that the lactic bacteria in milk are harmful when taken into the digestive organs; but most people do not like to drink sour milk. In recent years, we have had many newspaper articles on Professor Metchnikoff's method of preparing milk for preventing excessive development of decomposing bacteria in the intestines. Such bacteria produce poisonous substances which may be absorbed by the blood and cause ill health (auto-intoxication, meaning self-poisoning). The milk prepared by the Metchnikoff method is "soured" not by the ordinary lactic bacteria but by adding pure cultures of a certain species. Physicians are not yet agreed as to the medicinal value of such prepared milk; but one who wishes to try it should purchase the milk in which the proper bacteria have been grown. There are at drug-stores tablets which are said to be concentrated extracts of the proper bacteria, but they are not reliable.

(c) *Bacteria in Butter and Cheese.* — The peculiar flavors of butter and cheese are due to certain species of bacteria, and hence the scientific dairyman gives special attention to methods which will prevent the growth of undesirable species and favor the desirable ones. By using pure cultures of bacteria (and sometimes certain molds), it is possible to produce the desired quality of butter and cheese. The disagreeable flavor of butter made in many farm-houses is due to undesirable bacteria.

(d) *Bacteria in Vinegar.* — The change of alcohol into vinegar by bacteria has been mentioned in connection with yeast. "Mother-of-vinegar" is a mass of bacteria imbedded in a gelatinous substance which they secrete.

(*D*) Small pieces of the "mother" should be examined especially with the microscope.

(e) *Bacteria and Textile Fibers.* — Many fibers, such as

those of flax, hemp, and others obtained from the stems of plants, are obtained by rotting the stems until the surrounding tissues are soft. Bacteria do this work.

(*f*) *Useful Decomposition.* — While the action of bacteria in decomposing foods prepared for human use is harmful and financially a source of great loss, we should not forget that this same process of decomposition is absolutely necessary in order to prepare dead organic matter for use by plants. We repeat for emphasis the statement made elsewhere that but for the decomposing action of bacteria, aided by other micro-organisms, the world would soon be so filled with dead bodies of animals and plants that the carbon and nitrogen needed in the food supply of living things would be bound up in dead organic matter. Hence as decomposers of organic matter the bacteria are indispensable.

A splendid example of the usefulness of bacteria in causing decomposition is found in the latest methods for disposal of sewage in concrete tanks or reservoirs arranged so as to allow decomposing bacteria to grow rapidly. The result is that sewage is changed so that even pathogenic (disease-producing) bacteria are killed. Many cities now purify their sewage by this method before discharging it into rivers. For private sewer systems in villages and in rural districts, the best method consists in allowing sewage to run into porous drain-tiles laid a short distance below the surface in loose soil. In the soil around the tiles the decomposing bacteria flourish and convert the sewage into harmless substances which may be used by roots of plants. The old-fashioned cesspools are being superseded by modern bacterial methods, for cesspools do not favor rapid growth of bacteria, and moreover they are often deep enough to allow escape of dangerous sewage into subterranean water-courses.

Summarizing the useful aspects of bacteria, it is evident that *their usefulness far exceeds their harmfulness.* A few individual organisms may die from bacterial diseases, but the continuance of life on this planet depends directly upon the decomposing action of the bacteria, which prepare organic matter for use by plants. And quite apart from this all-important aspect of our relation to bacteria, their value in the other ways we have noted above far outweighs their harmfulness as producers of disease. Moreover, in the not distant future, when civilized people will carefully apply the already well-known biological laws (§§ 249–257) so that bacterial diseases will be kept under control, the usefulness of bacteria will attract more popular attention than at present, when the average citizen thinks of "germs" only as producers of disease.

(*b*) *Molds**

Most of the useful aspects of bacteria are well treated in Lipmann's "Bacteria in Relation to Country Life," and more briefly in Conn's "Bacteria, Yeasts, and Molds in the Home."

272. Study of Common Molds. — It is a well-known fact that when bread, cheese, or other foods are left for some time in a damp place, there appears upon the surface a mass of delicate threads or filaments, and the bread is said to be "molding" or "moldy." Soon the color of the moldy mass changes from white to black, blue-green, or brown; and according to the color, the names black mold, green mold, and brown mold are applied.

* Molds, mushrooms, yeasts, and their allies are commonly grouped under the name Fungi. They are all plants without chlorophyll, and hence different in the food supply from the lowest green plants (Algæ). For the position of these plants in the classification of the plant kingdom, see table in § 44.

(*L*) Examine pieces of bread on which black mold is growing. Break off pieces and note that delicate threads run through the bread (use a hand-lens). These threads are called *hyphæ*, and the entire mass of them is the *mycelium*. Starting on the surface, the mycelium grows numerous branches which penetrate every part of the bread. At the same time it secretes digestive substances which digest starch and other foods in the bread. These digested and dissolved foods are absorbed by the mycelium and used for growth.

The delicate threads seen above the surface of the bread are erect or aërial hyphæ; they are branches of the mycelium. Close examination with a strong hand-lens will show that the color of the mold is due to spherical bodies attached to the ends of the erect hyphæ. These bodies are the *spore-cases*, or *sporangia*, which are filled with spores (Fig. 76, *s*). Various stages in the development of the spore-cases show that they are formed by expansion of the ends of aërial hyphæ. The protoplasm inside these expanded ends divides into numerous small masses, each of which becomes a spore.

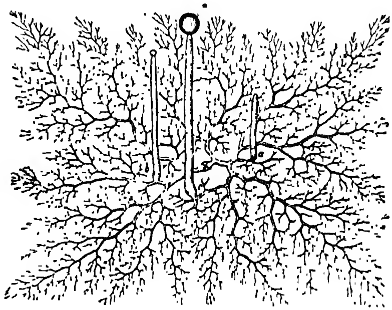

FIG. 76. A black mold plant formed from one spore in center. One mature aërial hypha with spherical spore-case (*s*), and two immature ones. Root-like structure is mycelium. (*From Kny.*)

Examine spores with high power of microscope. Notice the thick cell-wall, which is very protective against heat, drought, and other unfavorable conditions.

Examine green mold, especially noting the peculiar sporangia (Fig. 77).

(*D*) If some spores be placed in dilute sugar solution in a watch-glass, many of them will be found germinating after a day; and after several days much branching will produce an extensive mycelium (Fig. 76). Later, some aërial branches or hyphæ arise and form spore-cases. The entire mycelium and aërial branches with spore-cases which originate from a single spore, is a *mold plant* (Fig. 76). Usually such plants are closely interlaced, because many spores fall on the same piece of bread.

Molds grow best in a warm and damp place, as can be proved by leaving pieces of moist bread in two bottles, one of which is placed near a stove or radiator, and one in an ice-box. However, some molds will grow on foods kept for some time in the ice-box. In fact, many foods will spoil in ice-boxes and should be reheated to 100° C. two or three times per week.

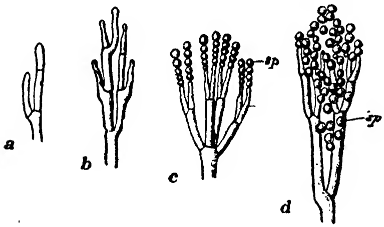

FIG. 77. Unlike the spherical spore-case of the black mold, the green mold forms spores (*sp*) at ends of branches of aërial hyphæ.

273. Experiments with Molds. — (*D* or *L*) Test-tubes ½ by 5 inches are best for these experiments, but bottles with mouths at least ½ inch in diameter will do. Cut some strips of bread ¼ by 2 inches in size, and place one in each of ten or more tubes, and add three or four drops of boiled water to each tube. Now, plug the mouths of the tubes with cotton-batting or absorbent cotton, making the plugs by rolling the cotton into a cylinder about two inches long.*

Sterilization. — It is probable that both the bread inside the tubes and the cotton have spores of molds on their surfaces, because spores are so abundant in ordinary buildings that practically everything exposed to air will have them. It is therefore necessary to kill all spores inside the plugged tubes, that is, to *sterilize* or to make the tubes *sterile*. This is best done by boiling or steaming (100° C., 212° F.), in a *sterilizer*. There are many sterilizers for laboratory and home use on the market, but one can be easily made from any tin bucket with a cover. Place in the bottom of the bucket an inverted tin pan two inches deep with holes in its bottom; and on this, place the tubes to be sterilized. Put in water two inches deep. For convenience in keeping mouths of test-tubes upward, they may be tied into bunches, or placed in small tin cans perforated with numerous holes. A layer of cloth or cotton between the glass tubes and the metal will prevent breakage.

* TO TEACHER: See the "Applied Biology," § 245.

Keep the water boiling (100° C.) for a half-hour. From time to time add more water (hot) so that the sterilizer will not "boil dry."

Label some of the tubes "sterilized once, 30 minutes." Set aside for observation from day to day. Do any molds appear on the bread in these? Conclusions?

Sterilize the unlabeled tubes again two days after the first sterilizing, and label "sterilized twice, total 60 minutes." Sometimes a third sterilizing is necessary to kill all the spores of molds.

Inoculation. — Take a tube which two or three days after the second or third sterilizing shows no sign of molds on the bread, and hence is probably sterile, and inoculate it as follows: Sterilize an inoculating needle (or a hat-pin, or piece of wire) by passing it quickly several times through the flame of a gas- or alcohol-lamp. Allow the needle to cool for a moment, and then touch the sterilized end carefully to a spot on moldy bread where there is only one kind of mold. Now, holding one of the sterile tubes in a horizontal position, quickly pull out the cotton plug, insert the needle, wipe it along one side of the piece of sterile bread, and then quickly replace the plug. Inoculate other tubes from other spots of molds, of different kinds if available, but take care to heat the wire of the inoculating needle before and after each tube is inoculated, otherwise you may mix several kinds of spores. Label tubes "black mold," "green mold," etc.

Do not be surprised if with all these precautions two kinds of molds appear in some tubes; for spores may have been left alive on the bread even after sterilizing, they may have fallen in when the tube was opened for inoculating, or more than one kind of spores may have been on the moldy spot touched with the needle. If only one kind appears, a "*pure culture*" has been secured.

Take two tubes which have been sterilized twice, remove cotton plugs, and blow into them some dust from top of furniture, door-frame, or window-casing; or sterilize an inoculating needle and with it transfer some of the dust to the sterile bread. Record result and conclusions. Why do foods mold quickly in a dusty pantry?

Leave the plugs out of two sterile tubes for several hours, and then replace. If molds develop, consider the possible source of the spores. A better way for this experiment is to use a flat dish, known as a Petri dish, made for such experiments (Fig. 78). Place a slice of moist bread in such a dish, sterilize twice, wait several days to make sure that the bread is sterile, then remove the cover

for several hours so as to expose the sterile bread to the air of the schoolroom.

A small tumbler or wine-glass may be used instead of a Petri dish. Place a piece of moist bread inside on the bottom of a tumbler, cover with a circular sheet of cotton-wadding which by two inches exceeds the diameter of the top of the tumbler, fold the edges of the cotton down, and snap a rubber band around it so as to hold it close to the top of the tumbler. Sterilize as in the case of the Petri dish.

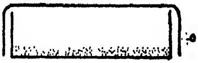

FIG. 78. Section of a Petri dish, for growing molds and bacteria. *c*, glass cover. The dots in bottom show position of gelatin, bread, or other food.

Canning Fruit. — The glass jars in common use are sealed air tight by means of a rubber ring. The above experiments suggest that the rubber is not necessary. The cap of an ordinary fruit-jar would protect the contents against entrance of spores if the jar and the fruit were thoroughly sterilized after placing the cap in position. But in ordinary household canning of fruits the sterilization (usually only once) is not perfect and the keeping out of air by the rubber tends to prevent the development of molds which require air in order to grow. Also, the rubber prevents hyphæ from starting on the outside and growing beneath the cover into the contents of the jar. This would surely happen if fruit juice ran down around the edge of the cover, for the juice would furnish excellent food for the growing hyphæ. This is why fruit in jars often remains sterile for months and even years, and then suddenly shows molds. The rubbers have softened, or loosened, or become moist, so that mold hyphæ have been able to grow into the jars; or the entrance of air may start growth of spores inclosed with the fruit. Hence jars of fruit should be kept in a cool and dry place unfavorable for growth of molds. Aside from this relation to molds, rubbers of fruit-jars also prevent evaporation of the fruit juices.

Rotting of fruit has been mentioned as due to molds. Take a perfect apple and inoculate it by sticking in several places with a needle which has been plunged into a very rotten apple. Take another perfect apple, bruise the skin on one side, and place it in a covered can or box in contact with a rotting apple. In both cases be sure there is moisture — the apples may be kept on wet cloth or cotton. Take another perfect apple, gently rub the skin in several places with a smooth stick which has been plunged into a rotting apple, so as to distribute spores over the uninjured surface of the apple, and set this one in a *cool and dry* place for comparison with the others. What are the conclusions regarding apples infecting each other? Why should injured apples be separated from perfect ones before packing? Why are apples bored by worms (larvæ or codling moth) and "windfalls" so liable to decay? Why should fruit-cellars be cool and dry? Since the spores usually mature after rotting is well advanced, it is evident that removal of windfall fruits, as by pigs living in orchards, prevents the enormous multiplication and distribution of spores of various molds which injure fruit.

Instead of pieces of bread called for in above experiments, a dilute sugar solution (three or four tablespoonfuls of sugar in a pint of water) may be used. Or use some diluted juice from canned fruits. It is interesting to prepare some tubes with the sugar solution and try all the experiments both with sugar and bread. Of course, any other organic material on which molds grow could be used in place of bread or sugar solution.

Write a short essay on "Molds in Relation to Preservation of Food for Human Use."

274. Allies of Molds. — Many fungi popularly known as molds, mildews, rusts, rots, blights, smuts, scabs, — all of them more or less closely related to the common molds which grow on bread and other foods, — are very important economically, because of their injurious effect on many cultivated plants. Several special agricultural books are devoted to these economic fungi, and some of the common varieties are briefly described in the "Applied Biology."

275. Useful Molds. — So many of the molds and their

allies are injurious from our human point of view that we must guard against the erroneous impression that all relatives of the molds are harmful. The following examples will suggest some useful aspects of the life of these lower fungi.

The common molds which cause decay oftentimes destroy materials useful as human foods and in other ways, but the same decay processes reduce useless organic matters to a condition which makes them available for plant food. For example, the vast quantities of leaves, stems, and other plant materials seen in late summer must be decayed before their elements can be used over again by plants, and in this decay many of the decomposing fungi aid.

Moreover, some fungi are useful because they destroy insects. House-flies are sometimes seen with delicate white threads projecting from their bodies. These threads bear spore-cases and a mycelium grows inside the flies. The spores which fall on other flies germinate, and so the disease may soon become epidemic. Other similar fungous diseases attack other insects, and millions of grasshoppers, chinch-bugs, and other destructive species are thus killed.

It should be credited to the molds that some of them produce the peculiar flavors of cheeses, such as Roquefort and Camembert. The manufacturers take particular pains to cause the growth of almost a pure culture of the proper kind of mold.

But although some of the molds and their allies may be useful from the standpoint of human interests, their usefulness is far overbalanced by their harmfulness, especially to the numerous plants which are important to the human food supply.

(c) *Mushrooms*

276. The term mushroom is here used as a general term including all forms popularly known as mushrooms and toad-

stools, for there is no scientific distinction between them. Formerly all edible fungi were called mushrooms, and all others toadstools; but many so-called toadstools are now known to be edible. Practically and scientifically, then, the two words are now used quite synonymously.

Structure of a Mushroom. — (*L*) Any common mushroom or toadstool will serve for this study. Specimens may be collected when available and preserved in 5 per cent formalin solution.

Examine a well-expanded specimen. Above ground it consists of a *stalk* and a *cap*. On the under side of the cap in most species are the gills, delicate plates radiating from the center. In some species there are numerous holes instead of the gills, and in others there are projections in the form of spines. If the cap be cut from the stalk and left for a few days with gills downward on a sheet of white paper, numerous dark-colored bodies (spores) will fall on the paper, leaving a print of the under side of the cap and showing the arrangement of the gills. Closer examination of the under side of the cap will show the spores on the sides of the gills. Make sketches in note-book.

Below ground the mushroom is attached to thread-like structures which are popularly called the rootlets, but they have no resemblance to real roots of higher plants, except that they are in the soil. These thread-like "rootlets" are *hyphæ* and the entire mass of them is known as a *mycelium* (see mold, § 272). From time to time new mushrooms or toadstools grow upward from the mycelium. At first the young mushroom is a small, compact, rounded body, concealed just below the surface until ready for expansion, when it absorbs water rapidly and may reach its full growth in a night.

Microscopic study shows the stalk and cap to be composed of closely packed and interwoven threads or hyphæ, which have the same structure as the hyphæ below ground. The part above ground is, then, a sort of branch of the subterranean mycelium.

Reproduction of Mushrooms. — A new mycelium is produced by germination of a spore which falls in a favorable place. The stalk raises the spore-producing cap above ground so that the spores may be more widely disseminated.

Cultivated mushrooms are grown from "spawn" which comes from seed dealers in the form of dry bricks composed of partially decayed vegetable matter. The spawn is really nothing but mycelium, either taken from old mushroom beds, or started by scattering spores over materials which are compressed and dried as soon as the spores have germinated and formed an extensive mycelium. Such bricks should be broken into pieces and planted in a bed of suitable soil with abundance of decaying organic matter. Concerning the cultivation of mushrooms, see Farmers' Bulletin No. 204 (free).

Physiology of Mushroom. — As described in § 62, plants without chlorophyll are like animals in that they must get their food from other organisms, either as parasites on living things (*e.g.*, dodder), or as saprophytes on decaying organic matter. The common mushrooms are usually saprophytes, but some of them grow as parasites on living trees (*e.g.*, shelf-fungi).

In their respiration mushrooms are like animals in that they take in oxygen and excrete carbon dioxide.

277. Lichens. — The familiar plants known as lichens, which in the form of grayish scales or moss-like masses grow on rocks and bark of trees, consist of two kinds of plants living together in intimate connection. One of the plants is a member of the Algæ (§ 44), and able to make carbohydrates from carbon dioxide and water; while the other is a fungus, which obtains its carbohydrate food from its associate. The main mass of a lichen is a dense mycelium similar in microscopic structure to some mushrooms, and

in this are the cells or filaments of the associated green plant.

Such a living together is an example of *symbiosis*. A similar association between a plant and an animal is that of the green bodies in Hydra (§ 116).

Reindeer-moss (a valuable food for reindeer) and Iceland moss (used in cooking) are lichens. Litmus (used for testing acids and alkalies) comes from a lichen. On the mountains lichens assist in weathering rocks, and thus forming soil. An edible form found on sandy deserts is called manna-lichen.

278. Economic Relations of Mushrooms. — *Food Value.* The words "economic relations" will probably lead most readers to think instantly of edible mushrooms. There are many thousand species of the group to which the common mushrooms belong, and many of them are edible. The fact is that they have little value as human food, but they are delicious as relishes. Concerning poisonous mushrooms, see § 233.

Effect on Timber. — More important economically than their food value is the destructive action of some mushrooms on trees valuable for lumber. The heart-wood is often found filled with white threads (mycelium) which so soften the wood as to make the lumber worthless. Hollow trees are usually due to such decay. The mycelium seen in the wood is connected with a shelf-like structure (often called shelf-mushroom or shelf-fungus) on the bark of trees. In walking through woodland one can easily find pieces of dead branches with small toadstools attached, and if these be split open, the white thread-like mycelium may be seen. These threads (hyphæ) enter trees through some injured tissue, such as a broken branch, gnawing by animals, or careless pruning which leaves large surfaces exposed. The

reason for painting all injured surfaces of trees with tar, cement, or paint is that these substances will keep out mycelia. Spores are abundant in the air and may at any time fall upon an injured surface, germinate, and form a mycelium which penetrates between the cells of the wood. It is an easy matter to keep mycelia from entering a tree at an injured place, but quite impossible to check them when once they have penetrated deeply into the plant.

The "dry rot" that often attacks the foundation timbers of houses and makes them unable to stand the strain of supporting buildings is due to the mycelium of a near relative of common mushrooms. The remedy for "dry rot" is ventilation of spaces beneath buildings and coating timbers with tar, crude oil, or creosote.

Some mushrooms have their mycelia penetrating the roots of trees, causing decay and weakening so that heavy winds uproot the trees.

Puff-balls, named because they puff out a mass of spores when ripe, are near relatives of the common mushrooms. Their mycelia grow in rotten logs and humus (decaying vegetable matter). They contain numerous small cavities in which spores are formed. Some of the puff-balls are edible in the young state.

(*d*) *Yeast Plants*

279. The Cause of Fermentation. — It is a well-known fact that liquids containing sugar, such as juices of grapes, apples, and other fruits, undergo a change called *fermentation*. The result of this process is the production of alcohol and an invisible gas (carbon dioxide), which causes effervescence of the fermenting liquid. No other method of producing alcohol is known to occur in nature; and so for

thousands of years fermentation has been used in making wines and other alcoholic beverages from fruit juices. It was not until the nineteenth century that the microscopic yeast plants were recognized as the cause of fermentation; and the experiments performed by the great French naturalist, Louis Pasteur, between 1855 and 1865 will always be famous as having placed our knowledge of fermentation processes on a thoroughly scientific foundation.

280. Study of Yeast Plants. — (*L*) Scrape some particles from a cake of compressed yeast, mix with a drop of water on an object-slide, and gently lower a cover-glass into position. Prepare another slide by mounting a drop of molasses-solution (water 10 parts, common dark-colored molasses 1 part) in which some scrapings of compressed yeast were placed on the previous day and the liquid kept in a warm place (70° to 90° F.). It is best to draw up with a rubber-bulbed pipette, or with a dipping tube, some of the white sediment in the bottom of the bottle containing the molasses-solution.

Examine the slides with high power of microscope. Small oval translucent bodies, some isolated, some united into groups or chains, will be seen. Each oval body is a yeast plant; and it is a single cell, consisting of protoplasm with droplets of fluid and a nucleus visible only when stained. The chains are due to reproduction by formation of buds. By comparing the sizes of the cells in a chain, it is possible to determine the order in which the buds were formed (Fig. 79). The cells of a chain finally become isolated; and each may grow into a chain of new cells when food is available. An abundance of long chains indicates that yeast has been growing rapidly; compare some taken directly from compressed cakes with some which has been in molasses-solution.

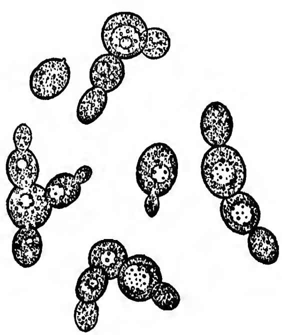

FIG. 79. Yeast cells, two cells beginning to bud, and three chains of cells, formed by repeated budding. Nuclei not shown. Drops of fluid are in centers of some cells. (*From Sedgwick and Wilson.*)

Experiments with Yeast. — (*D*) Experiments to show effect of food upon growth of yeast, the effect of heat, the nature of the gas evolved, the presence of alcohol in fermenting fluids, the preservative effect of dense sugar solutions, and yeast in bread-making are outlined in § 251 of the "Applied Biology," and should be demonstrated if time allows.

281. Physiology of Yeast Plant. — The plant is a one-celled organism, without chlorophyll, and for food is dependent upon sugar or starch built up by other plants. It is therefore a saprophyte like the molds, mushrooms, Indian pipe, and many other plants without chlorophyll. Pasteur showed that yeast plants must have nine elements in their food; namely, carbon, hydrogen, oxygen, nitrogen, calcium, sulphur, phosphorus, potassium, and magnesium. These are necessary for the formation of new yeast protoplasm, that is, for growth; and if fermentation is also to take place, sugar (or starch convertible into sugar) must also be present. Fermentation, which changes sugar into alcohol and carbon dioxide, is due to an enzyme secreted by yeast plants.

Yeast plants grow best at about 70° to 90° F. They are quickly killed at the boiling temperature, and hence it is quite easy to preserve sweet (unfermented) cider or grape juice in bottles. Fermentable foods may be preserved at the freezing temperature, which is colder than that of common ice-boxes.

Yeast plants can withstand partial drying in cakes of dry yeast, but after some months all the cells are dead in such cakes. Wild yeasts can live in the dust on fruits, or on the surface of the soil in orchards and vineyards, ready to begin growth as soon as the bruised or crushed fruit allows the yeast plants access to the juices. Dry yeast cells float with dust in the air, and this explains why sterile fruit juices

(*e.g.*, boiled cider) of sugary solutions will soon ferment after exposure to ordinary air.

282. Economic Relations of Yeasts. — It is only necessary to allude briefly to the vast industries of manufacturing bread and alcoholic beverages which are dependent upon production of alcohol and carbon dioxide by yeast plants. So great is the importance of pure yeasts in these two industries that enormous factories, costing immense sums of money, are devoted to raising yeasts.

Apart from alcohol in beverages and in medicine, it has long been invaluable in varnishes and numerous other compounds used in mechanic arts. Recently it has been coming into prominence as a cheap source of energy for engines, burners, lamps, etc. It is possible to make alcohol cheaply from much plant material which, on the ordinary farm, goes to waste (unmarketable fruits and grains); and it is probable that before many years pass the making of alcohol for mechanical purposes will be a vast industry in agricultural regions.

Vinegar, which is used so extensively as a condiment and for preserving certain foods for human use, is best made from alcohol derived from fermented fruit juice. For example, yeast plants ferment the sugar of apple cider and form alcohol; and the vinegar bacteria, of which there are millions in "mother-of-vinegar," ferment the alcohol into acetic acid, which gives vinegar its acid qualities.

On the harmful side, we must mention the undesired fermentation of fruits and sugary mixtures prepared for human food. However, we have seen that heating to near boiling will check such action of yeast. Sometimes yeasts cause undesired fermentation in milk and cheese in dairies.

We must conclude, then, that on the whole, yeast plants are decidedly useful as producers of alcohol and carbon

dioxide. Most of the bread-making since human civilization reached a stage where attention began to be paid to preparing the best possible foods, has depended upon yeast plants. Quite apart from the question of the harmful use of alcoholic liquors, to be discussed in the last part of this book, there can be no question concerning the value of alcohol for many other purposes. The usefulness of yeasts forms a decided contrast to the harmfulness of the molds.

Reading: Section II in Conn's "Bacteria, Yeasts, and Molds in the Home."

283. Economic Relations of the Algæ. — A large number of simple plants that have chlorophyll are included in the group Algæ. The most familiar examples are the sea-weeds and the green plants that form a delicate coating on the walls of glass aquaria.* Some authors classify all the plants that are lower than mosses in two groups, the Algæ which have chlorophyll and the Fungi which have not.

Probably the greatest value of the algæ lies in the fact that they make food for animals. This may be observed in any aquarium where snails rasp off and eat the green algæ on the glass. Numerous small animals eat algæ, and these animals may serve as food for still larger animals. Immense quantities of these low plants are found in the ocean as far down as light penetrates. Even some large animals, *e.g.*, certain fishes and whales, have strainers in their mouths which enable them to collect large quantities of very small organisms, some of them animals and some plants; but especially do small animals which feed on simple algæ serve as food for the larger animals. It is now quite certain that

* To Teachers: Specimens of the Algæ, such as the filamentous Spirogyra or Vaucheria, the green coatings of glass aquaria that have stood exposed to light, and dried or preserved specimens of sea-weeds, should be exhibited for the sake of general acquaintance.

directly or indirectly these simplest green plants play an important part in the food supply of aquatic animal life, much of which is of use to man. In this line the simple algæ have great economic importance.

Many kinds of large sea-weeds have economic uses. Thus iodine is prepared from the ash obtained by burning sea-weeds; and formerly this was also the chief source of sodium carbonate, from which baking soda is made. Certain sea-weeds are used as food by Chinese and Japanese and by the natives of the Malay Archipelago. Agar-agar and Irish moss, both used in preparation of jellies, are made from certain kinds of sea-weeds. Finally, in some places near the sea, the sea-weeds cast up by the waves are used as soil fertilizers. It is now proposed to harvest with dredges a species that is abundant along the Pacific Coast in order to get its potash for agricultural use, but it is not yet certain that this will be profitable.

284. Uses of Mosses. — The mosses are higher than the algæ and fungi, but lower than ferns. They are common on exposed and barren hillsides, in bogs, in cold northern regions, in forests, and even in water.

One of the most useful mosses is the bog- or peat-moss (Sphagnum) which grows luxuriantly where most other plants cannot live, and its growth gradually fills the bogs with dead vegetation called peat. This does not decay rapidly because the water in peat-bogs is somewhat antiseptic (*i.e.*, prevents the development of bacteria which cause decay elsewhere). In Ireland and some other countries the peat which is extensively used as fuel is composed largely of species of peat-moss. The American peat contains many other aquatic plants. The floating islands in some lakes and the quaking soil in marshy regions are masses of dead vegetation, often largely peat-moss, which have collected

some silt and thus formed soil on which other kinds of plants grow. Sphagnum moss is extensively used for packing plants for shipping; and in greenhouses for filling hanging baskets for ferns and orchids, for mixing with soil to prevent it from packing and to make it hold water, and for covering the soil in flower-pots.

285. Economic Relations of Ferns and their Allies. — These plants form a division called Pteridophytes. Many leaves and stems of fern-like plants are found as coal fossils, splendid specimens of which are on exhibition at natural history museums.

At the present time little use is made of ferns except for ornamental purposes, for which their foliage is unsurpassed. Many tropical species are kept in greenhouses, and several species have long been favorite house-plants. Various kinds of the related club-mosses (lycopods, not true mosses) are also used in the same way. Some of them are called "ground pine." The curious plant sold under the name of "resurrection plant" is one of the little lycopods.

One fern contains in its stem a powerful drug, known in pharmacy as "extract of male fern," and often used for expelling tape-worms and round-worms from the intestines.

The horse-tails (equisetums) are relatives of the ferns. They were known as "scouring rushes" in the pioneer days in America, because their stems were used to scour pewter and brass utensils. The scouring property depends upon silicon particles in the stems (easily demonstrated by burning). Many of the equisetums, some tree-like, flourished during the coal age (carboniferous). They are now common in damp sandy places along railroads, ditches, and highways.

286. The economic importance of the seed-plants is so vast that a special book would be required to discuss it adequately. Here we can only point to the fact that the

great majority of plants useful to man are seed-plants. Practically all of our plant food-supply and that of our domesticated birds and mammals; all of our forests useful for lumber; all of our plants which produce fibers (cotton, hemp, linen, etc.); most of the plants which produce drugs and other special substances; and almost all of our ornamental plants belong in the great group of seed-plants or flowering plants. The mere mention of food plants, fiber plants, and lumber calls to mind the vast agricultural and manufacturing industries which have been built up on the basis of seed-plants. In fact, the foundation of the wealth of the civilized nations is in agriculture, which is primarily the business of producing useful seed-plants. The useful parts of seed-plants are seeds, roots, stems, flowers, and fruits. We have time for only a few examples of each of these.

Seeds

287. Useful Seeds. — Quite apart from the functions of seeds in propagation of new plant individuals, many of them are useful to us because they contain foods, oils, and medicinal substances. Examples of seeds valuable in our food-supply or for our domesticated animals are beans, peas, lentils, corn, wheat, rye, oats, barley, rice, buckwheat, peanut, many true nuts, cotton, cocoa-bean, vanilla-bean, coffee. Seeds with useful oils are: flax, furnishing linseed oil used in paints; castor-oil seed, whose oil is a lubricant. Seeds with medicinal value are numerous; examples are mustard, squash, castor oil, and anise. The great majority of species of the seed-plants, or flowering plants, do not produce seeds directly useful to man.

Roots

288. Roots as Food. — In addition to their prime purposes — anchoring plants to the soil and absorbing water with certain plant foods in solution — many roots are directly useful because they contain food for man and domesticated animals. Examples are beets, mangels (a kind of beet), turnips, ruta bagas (a kind of turnip), parsnip, radish, salsify, sweet potato, carrot. However, the primary purpose is not storage for man and animals, but for the plants' use later. Many plants which thus store food in roots use it in the second year for the development of flowers and seeds, and then the plants die. Such are *biennials* or two-year plants. Other plants which live many years (*e.g.*, rhubarb and asparagus) store food in the roots every summer to be used for early growth in the next spring.

289. Root-tubercles. — These are small rounded masses found on roots of legumes (beans, peas, clovers, vetches, alfalfa). Only by the aid of the bacteria which live in the root-tubercles is it possible for plants to make use of the nitrogen which constitutes over two-thirds of the air. These bacteria have the peculiar power of combining nitrogen with other elements derived from the soil, and the nitrogen compounds thus formed are absorbed by the roots and used by the plant just as it uses the nitrogen in manures and in such soil fertilizers as nitrate of soda.

290. Parasitic Roots. — Many species of plants have peculiar roots adapted for penetrating the epidermis of other plants and thus forming a close attachment for absorbing the necessary foods. Examples are the mistletoe, which grows on the bark of oak, apple, and other trees; and the common dodder, which has root-like branches penetrating other plants from which it can absorb suitable foods. These

are cases of plant parasites; and this condition in which one plant (the *parasite*) absorbs its food from another plant (the host) is *parasitism.* The mistletoe has pale green leaves and can make some starch, so it is only in part a parasite. The dodder has no roots in the soil, only some very small scale-like rudiments of leaves without chlorophyll, and a yellow, string-like stem with very little chlorophyll. Evidently it must depend upon other plants for the foods which ordinary plants get from the soil and make in their green leaves. In recent years the dodder has been accidentally planted in many fields by seed mixed with those of clover and alfalfa, and has caused great damage by absorbing food from the plants with which it makes a root-like connection. For more facts concerning the relation of this weed to agriculture, read Farmers' Bulletin 306, "Dodder and its Relation to Farm Seeds."

291. Soil Binding by Roots. — After any heavy rainstorm one can see that bare soil, such as that on roads and cultivated fields, has been washed away where water has flowed rapidly, while grassy sod has not been so affected. This illustrates an important work of roots, that of holding particles of soil together. Cutting a forest from a hillside or sloping land allows rapid washing, and large tracts of valuable land have been ruined by removal of fertile soil and by formation of deep gullies.

The same kind of erosion often occurs when cultivated fields are bare during the winter. Even if deep furrows or gullies are not formed, it is evident that the muddy water which always flows down bare slopes is carrying away large quantities of the fertile top soil. This has not been sufficiently understood by many farmers in the past, but its importance has been so clearly demonstrated that the scientific farmer of to-day tries to protect soil against erosion during

the winter by planting some winter crop in late summer, either after harvesting a cultivated crop like corn and vegetables, or between the rows after the last cultivation, or in cultivated orchards and vineyards. This winter crop may be wheat, rye, or grasses to be harvested in the following summer, or a "cover crop" of certain clovers, vetches, rye, and other plants which make great root growth in the autumn, largely prevent erosion by the rains of the winter and early spring, and add to the fertility of the soil if plowed under in the next year's cultivation.

292. Propagation from Roots. — While many stems readily develop roots, most roots do not form stems, and hence cannot be used for propagation of new plants. Exceptions are sweet potato, which is a thickened root, and roots of the osage-orange tree. In order to start new plants of sweet potato or osage-orange, it is simply necessary to bury root-cuttings in favorable soil. A sweet potato will form stems on any part of its surface; but roots like carrot, beet, horse-radish, and turnip soon die when the stem end or bud is removed. Some plants (*e.g.*, dahlia) form a cluster of roots at the base of the stem, but each one of these can grow a new stem only at the upper or stem end. Many of the root-like structures from which new stems originate are really underground stems (*e.g.*, the ordinary potato).

Stems

293. Useful Stems. — The most important stems are those of trees used for wood, paper pulp, charcoal, and lumber. Certain stems are used in our food-supply. Asparagus plants above the soil are all stem, the leaves being reduced to scales. The common potato is a thickened underground stem stored with an abundance of starch. Much of our ordinary sugar is made from the extracted juice of the stems

of sugar-cane, but some is made from roots of sugar-beet. Maple sugar is from the sap drawn from trunk (stem) of a maple tree, usually the hard maple, but sometimes the soft or red maple. Ginger " root " is really an underground stem. Cinnamon is the bark of a tree. The edible parts of many plants, such as spinach, onion, cabbage, celery, and the grasses used as hay for animals, consist in part of stems with the attached leaves. Among other stems whose products are useful are certain pine trees whose bark when injured exudes tar, turpentine, and resin. Rubber comes from certain species of trees belonging to the fig family. Quinine is made from the bark of the cinchona tree. Hemp and flax fibers are obtained by rotting the stems of the plants so as to free the fibro-vascular bundles from surrounding tissue. Straws used for hats and many other purposes are the stems of rye, wheat, or other members of the grass family.

The value of many stems, such as those of trees grown for lumber, fruit, or ornamental purposes, depends largely upon their habit of growth and the consequent form and structure of the stems. In order to understand many economic problems relating to stems we must study them more carefully than we did in the first lessons on plants.

294. Twigs.* — This is a popular term applied to pieces of stems, or to small branches of trees and shrubs. They are very convenient for study, because they illustrate on a small scale the general structure of the entire stem of the plant from which they are taken.

(*L*) Twigs of horse-chestnut, hickory, ash, box-elder, ailanthus, linden, sycamore, etc. Note that the bud at the end of the twig (*terminal bud*) is larger than the buds along the sides (*lateral buds*).

* To Teachers: If most of the students in the class have studied twigs and buds in the nature-study of the elementary school, this exercise and the following on buds should be given but brief attention.

Observe the positions of the buds along the stem (see Fig. 80). Observe the large horseshoe-shaped scars immediately beneath the buds. These are *leaf-scars*. What is the position of a bud with reference to the leaf? Look for very small scars scattered irregularly over the stem; they are *lenticels* or breathing pores. The nature of the rings of scars will be made evident after a study of the bud. Often one can find a large scar in the fork of a horse-chestnut branch; this is a flower-scar. On a much larger twig, observe the arrangement of the branches — how does it compare with the arrangement of the buds already noted? This is what we should expect if the branches are merely developed buds, as stated in the definition of a bud in the next section.

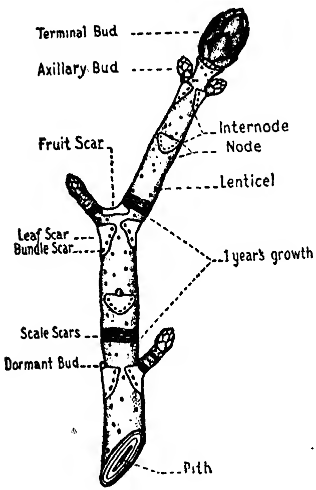

FIG. 80. Twig of horse-chestnut. (*From Blakeslee and Jarvis.*)

Make a sketch of the twig which has been studied, showing as many of above points of structure as possible. Compare with as many twigs as possible — lilac, apple, cherry, tulip-tree, butternut, beech, and others named above.

295. Buds. — A bud is a growing point on a plant which, when conditions are favorable, will develop into a leafy branch, a flower, or both. In temperate regions where plants must withstand a long, cold winter, trees and shrubs have formed the habit of covering and protecting their growing points with scales, hair, or gummy substances. The horse-chestnut bud is a good example of a scaly or *winter bud*, and similar ones can be seen on any of our hardy shrubs or trees. In annuals and herbaceous perennials of temperate climates and in tropical countries where the grow-

ing season is not interrupted by a winter season, with its sudden changes of temperature and moisture, the buds as a rule have either very little covering of scales or hairs, or none at all (*naked buds*).

(*L*) Buds of horse-chestnut, hickory, lilac, elm, or any large bud. Examine horse-chestnut buds and note that they are all covered with sticky brown scales which overlap as do the shingles on a house. Examine a bud cut longitudinally. Suggest a use for the sticky substance. Carefully remove the scales from a bud and observe the ring of scars left on the stem. This marks the end of the year's growth of the stem. Look along the stem for other similar rings of scars — how many do you find? What relation does the number of such rings of scars bear to the age of the twig?

Note that the bud-scales are arranged in pairs, and that they become softer and more leaf-like as you approach the center. When all the scales have been removed, there remains a soft, woolly object, the young stem and leaves. Suggest a use for the hairy substance. Sometimes the terminal bud is a flower-bud. Compare what you have found in a closed bud with what you find in an opening bud on a twig which has been standing in water in a warm room. Observe that such a bud has swelled, some of the outer scales have fallen off, leaving a fresh ring of scars on the stem, the inner scales have become larger and more leaf-like, the shoot has elongated, the leaflets are separating and unfolding.

Compare buds from various trees and shrubs.

Leaves are formed folded in buds. This is necessary for two reasons: (1) leaves in a bud must take up as little space as possible; (2) young, tender leaves must have as little surface as possible exposed to the dry and cold air of winter. The folding of the leaves in the bud is known in botany as vernation.

Examine buds of various trees and shrubs such as lilac, tulip-tree, hickory, beech, currant, etc., for types of vernation. Also examine naked buds.

Bud-like Structures. — The cabbage head and the onion bulb both illustrate the structure of a bud; but it should be noted that they are not true buds, for they represent fully developed shoots with very short stems.

(*D*) Cut lengthwise through center of an onion and a small cabbage.

296. Position of Buds and Branches. — Some buds are abnormal in position and are known as *adventitious.* They develop on some trees when large branches have been cut off, and advantage is taken of this fact by pollarding willow trees and thus causing them to produce from adventitious buds the straight and slender branches suitable for making baskets. Some trees are pollarded in order to get ornamental trees with rounded, bushy tops.

Opposite Branching. — When the buds are in pairs at each node and opposite each other, there is a four-rowed arrangement on the twig; but owing to the failure of some of the buds to develop and the death of some young twigs, this arrangement is seldom perfect on fully grown branches. As examples, observe maple, ash, horse-chestnut, and lilac.

Alternate Branching. — When the buds are arranged one to each node, there may be two, three, five, or more rows. In passing from any bud to the next above on the stem we go spirally around the stem. Examples are hickory, elm, beech, ailanthus, and walnut. Alternate is more common than opposite branching.

297. Tree Forms. — If the terminal bud takes the lead in growth, the result is a tree like the spruce or hemlock, in which the straight main trunk can be traced to the very top of the tree, and with relatively small lateral branches. When the branches from the lateral buds develop rapidly, the result is a round-top tree, like the apple, in which the

main trunk cannot be distinguished from main branches. Most of our common forest trees are intermediate between these two types. Observe various trees and decide to which of these classes they belong. Also notice that the characteristic contour of a tree or shrub depends both upon its mode of branching and upon the angle which the branch makes with the main stem, *e.g.*, compare Lombardy poplars with ordinary trees of our forests and parks.

298. Growth of Stems in Length. — Elongation is most rapid just below the growing tip of stems and their branches. If one measures the distance between marked branches on a young fruit-tree in early spring and again in autumn, it will be found that the older branches have not grown farther apart or higher from the ground; but the branches which appear during the growing season grow farther apart during some weeks while the tissues are soft. This is a matter of practical importance for one who cultivates trees. In pruning, branches must be left at the height where it is desired to have them when the tree is fully grown. Also, by cutting the ends (terminal buds) of the main stem and of its branches it is possible to control the height of the tree, and thus keep fruit-bearing branches near the ground for convenience in collecting fruit.

299. Growth of Stems in Diameter. — It is a well-known fact that the trunks of our common trees continue to increase in diameter. This is due to the formation of new outer layers of wood by the cells of the cambium (§ 35). New inner layers of bark are also formed by the cambium. Commonly one layer is formed each year, and results in the rings of growth seen in transverse sections of many trees (Fig. 81). A hand-lens examination of a section of oak, or other wood with clearly marked rings, will show that the lines between the rings are marked by large wood tubes.

These are formed while the stem was growing rapidly, usually in the spring.

The age of a tree cannot always be accurately determined by counting the "annual" rings, for it has been found that sometimes two rings are formed in a single year. This may happen if growth is checked for a time in early summer, as by drought or destruction of leaves by caterpillars, and begins again later in the summer.

The stems of plants whose structure is like the corn stalk * have their fibro-vascular bundles arranged irregularly as in Fig. 11, instead of in rings as in the ordinary trees. Such stems do not increase in diameter each year by addition of layers to the outside of the wood, but instead they grow practically to the full diameter during primary growth, *i.e.*, while elongating. Thus the trunks of palms and cocoanut trees are nearly the same diameter almost to the leafy top; and although these trees continue to grow for many years, there is little increase in diameter except near the growing top. Such increase as does occur, as in some palms, is due to expansion of the first-formed cells, not to new layers of cells added between the bark and wood.

300. Structure of Stems of Common Trees. — (*L*) Materials: Stems of oak, pine, beech, maple, and as many others as obtainable, selecting stems of various diameters, from a half inch to two inches or more. These should be cut off with a fine-tooth saw and then smoothed by rubbing on sandpaper which has been glued or tacked to a board. Also, some sections or cut-ends or twigs, one, two, and three years old. In many high schools the boys who know how to use carpenters' tools prepare a neat collection of woods. Dead and well-dried ("seasoned") branches are best.

The hand-lens shows that the *annual rings* are marked off by large pores (the *wood-tubes*). Compare stems of varying diameters,

* The seed-plants which have stem structure like corn belong to the group of the monocotyledons (§ 44), while the ringed type of stem is found in the dicotyledons.

and count the rings. Each season's growth begins with the large tubes, formed when growing rapidly in spring, and extends outward to the next ring of large wood-tubes. In many woody stems some pith remains in the center.

Most woody stems have delicate radiating lines, the *pith-rays* or *medullary rays*, which are so named because they are composed of the same kind of cells as those found in the central pith.

Notice the difference in color between the outer and inner annual rings. The lighter colored outer part of the wood is the *sap-wood*, so called because it is active in transporting water and in freshly cut stems appears to be filled with sap. Some of its cells contain living substance. The darker central wood is the *heart-wood*, composed entirely of dead cells. How do you explain the fact that many large trees are hollow (because the heart-wood has rotted or been burned away), and yet they appear to be healthy trees?

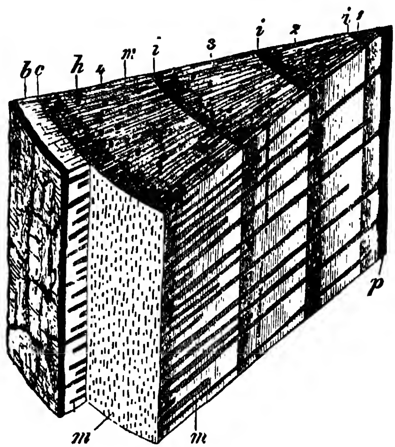

FIG. 81. From four-year-old pine stem cut in winter. Annual rings (*1, 2, 3, 4*); pith-rays (*m*); cambium (*c*); bark with bast (*b*); lines between wood of successive years (*i*); center of stem (*p*). (*From Strasburger.*)

(*D* or *L*) Split blocks from stems of various kinds of trees (especially oak, chestnut, beech, ash, pine) through the center, and plane the cut surfaces. The section thus made is *radial.* Parallel to the cut surface of one of the halves plane off the bark until some heart-wood is exposed. This surface will be a *tangential* section. In the radial section the pith-rays will appear as glossy plates of wood, and in the tangential section it will be evident that each ray extends some distance up and down the stem. Evidently the delicate radiating lines or rays seen in the transverse section were simply the edges of flattened plates which are placed vertically and radially in the stem.

(*D* or *L*) Examine the inner and outer layers of bark in various woody stems. Soften pieces of bark by long soaking and boiling in water, tear them into pieces and observe the position and direction of the fibers. Some of these are bast-fibers (elongated cells), which have been mentioned as of great value in the textile industries, *e.g.*, flax (linen), jute, ramie, and hemp are all obtained by rotting the bark of certain plants and then separating the bast-fibers.

301. Grafting and Healing Wounds on Stems. — The power of growth of the cambium is well illustrated in these two processes. If two branches of a tree be scraped down to the cambium and the wounded surfaces fastened together, the rapid growth of cambium cells will cause a grafting or union of the two. Examples of this are sometimes found in a forest or orchard, for branches often grow so near together that the swaying by the wind wears away the bark, exposes the cambium, and allows the two branches to grow together. Two small trees may so grow together.

The observation that stems will grow together or naturally graft probably led to artificial grafting of fruit trees. Essentially all grafting consists in bringing the cambium layer of a piece of twig with a bud (scion) from one plant into contact with the same layer on a stem of another plant of the same or sometimes a closely related species. Various ways of doing this are illustrated in Fig. 82. Grafts are usually placed on young plants near the roots ("root-grafting"), so that after the graft grows and the original stem is cut away only the variety of the graft will be represented in the stem above ground. Old trees are grafted by cutting off branches ("top-grafting") and inserting scions or grafts. If a new branch grows below the graft, it will bear fruit of the original variety.

Budding is essentially the same as grafting, but a single bud with a slice of bark is placed in contact with the cam-

bium of another tree, and after the bud grows into a stem the original stem is cut away (Fig. 82, lower row).

The growth of new tissue which takes place in the healing of wounds, as after pruning or breaking of limbs by wind, is essentially the same as in grafting. A ring of new tissue (callus) forms at the bark and tends to grow over the entire wound.

In cases where very large limbs have been cut off, the wood may decay before the cambium has been able to form enough new tissue to cover the wound completely. The remedy is (1) prevention of decay by painting or tarring all injured places so as to keep out the bacteria and molds which cause decay; and (2) if decay has already started, the softened wood should be cut out and the cavity filled with tar or water-proof cement.

302. Pruning of Stems. — Unnecessary and injured branches of trees, shrubs, and vines should be cut off. Un-

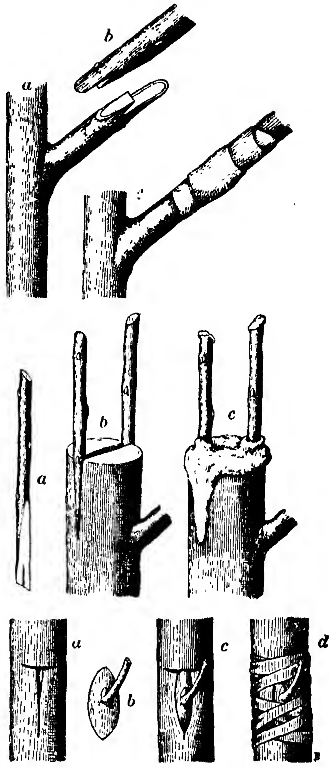

FIG. 82. Upper row — whip- or tongue-grafting. *a*, stem or stock; *b*, scion or graft; *c*, united and wrapped. Middle row — cleft grafting. *a*, scion; *b*, two scions inserted in cleft; *c*, waxed. Lower row — budding. *a*, stem cut to receive bud (*b*); *c*, bud inserted beneath bark; *d*, wrapped. Note in all the figures that cambium of scion and stock meet. (*U. S. Dept. Agriculture.*)

pruned fruit trees develop too many branches, and grow too high for convenience in spraying against fungi and insects or in picking fruit.

Pruning is now so well understood that a gardener can make a young tree take almost any desired shape by simply removing buds and branches which are not wanted, and thereby forcing growth in other directions. For example, pruning off a terminal bud makes the lateral branches grow. See Farmers' Bulletin No. 181.

Nature's method of pruning by crowding out superfluous branches is well illustrated in any dense wood. The shaded branches soon die and decay, and the result is the growth of long, straight stems with living branches near the top only. Why are trees set close together in young forest plantations?

Pruning trees and shrubs at planting time is of great value, in that it reduces the number of leaves until the roots can get well established in the soil. Unless the leaf-surface is thus reduced, evaporation is likely to be greater than can be replaced by absorption of water by the roots. It is difficult to transplant evergreens, because pruning would spoil the form of these ornamental trees, and the leaves cause excessive evaporation before new roots are established in the soil.

303. Duration of Life of Plant Stems. — It is a matter of common observation that some plants live only one year and that others live many years. In many cases this is of great economic importance. All plants of which the life of a generation, beginning with the seed and ending with death of stem and roots, comes within a year are called *annuals*. That is to say, an annual plant is one which completes its life-history by starting from seed, producing seed, and dying, root and all, within a single year. Other plants (*e.g.*, beet, cabbage, thistle, mullein) start from seed one year, the roots

and base of the stem live over the winter, and in the second summer they blossom, produce seed, and then die. Such two-year plants are *biennials.* Still other plants (especially trees and shrubs) live more than two years; and such plants are *perennials.* Some of these have a soft stem which cannot withstand the winter, but the underground parts are hardy and new stems form above ground in each growing season. Examples are peony, golden-rod, hollyhock, asparagus, violet, dandelion, buttercup, and most common grasses of our lawns and meadows. Such plants are called *herbaceous* perennials. Many of them are short-lived; for example, the best crop of red clover is grown in the first and second years, and after that the roots are unable to produce luxuriant growth of stem and leaves and gradually die out, giving place to grasses and weeds.*

304. Underground Stems. — Many plants have their main stems underground. Three common forms of such stems are rootstocks, tubers, and bulbs.

Rootstocks. — These are root-like stems which grow in the soil. Many ferns, grasses, sweet flag, golden-rod, quack-grass, peppermint, iris, Solomon's seal, and trilliums are examples of common plants with rootstocks (rhizomes). That these are not true roots is shown by the presence of buds and by the formation of branches and leaves. Solomon's seal (Fig. 83) is especially good for study. Its rootstock sends up an erect branch every spring which becomes the above-ground stem with leaves. All the above-ground part of the plant is herbaceous

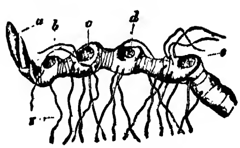

FIG. 83. Underground stem of Solomon's seal. *a*, terminal bud; *b*, *c*, *d*, *e*, leaf-scars of former years; *r*, roots.

* The duration of other useful plants is considered in § 168 of the "Applied Biology."

and dies in autumn. The seal-like scars on the rootstock mark the positions of above-ground branches in successive years. The oldest portion of the rootstock dies and decays; and some plants have short rootstocks, because the part which is more than a few years old has died and decayed.

Tubers. — Many of the rootstocks mentioned above store food, but do not undergo noticeable thickening at any particular point. In some plants storage of food in underground stems causes great enlargement and produces tubers (*e.g.*, the common potato and Jerusalem artichoke).

(*L*) Examine a tuber of potato, or artichoke. Note the point where it was attached to the main stem of the plant. Examine the "eyes," which are buds. Each "eye" is capable of developing a new plant, and hence to avoid having too many plants in one place gardeners cut tubers into pieces, each having two or three "eyes." Dig up a potato plant, and note position of the old and the new potatoes.

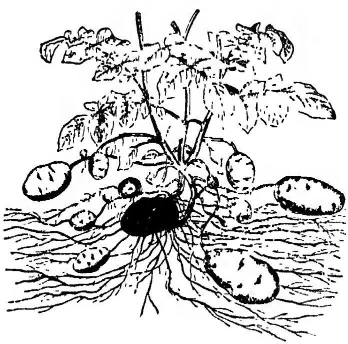

FIG. 84. Potato plant, developed from old tuber in center. The new tubers are thickenings of underground branches of the stem. (*From Strasburger.*)

Bulbs. — The onion is a good example of a bulb. A longitudinal cut through the center shows it to be a short stem surrounded by thick layers of modified leaves. Indian turnip (Jack-in-the-pulpit) and crocus have similar short and bulb-like stems, but they are solid and not composed of layers like the onion. Such solid, short, underground stems are often called corms; but there is no sharp distinction and corms are often called solid bulbs.

"*Stemless*" *Plants.* — Many common plants (*e.g.*, dande-

lions, plantains) have short stems and are often incorrectly said to be "stemless."

305. New Plants from Stems. — Strawberries, red raspberries, currant, and gooseberry are examples of numerous kinds of plants which have some branches either lying on the surface of the soil or creeping underground, and which form roots and develop new plants. When these branches are underground, gardeners call the new plants which come up "suckers."

306. Economic Value of Wood Structure. — The usefulness and consequent monetary value of lumber depend upon the nature of the various structures seen in the sections of stems. For many purposes hardness and strength combined are desired (*e.g.*, white oak for wagon-axles, hickory for ax-handles and wheel-spokes). Sometimes a light, elastic, straight-grained wood is wanted; and so ash is most common for the long handles of hoes, shovels, pitch-forks, etc. Woods which resist decay because they contain resins, oils, or other protecting substances are needed for fence-posts and telephone poles; and for such purposes cedar, chestnut, oak, mulberry, and black locust are usually preferred. White and red cedar, cypress, and redwood make the best shingles now in the market. For some purposes wood softer than oak is desirable because easy to work — carpenters charge much more for working oak than for soft woods like white pine. Hence pine, hemlock, spruce, redwood, basswood, tulip-wood or whitewood, cedar, sweet gum, and poplar are used for numerous purposes where soft and light wood will serve. For high-grade furniture, woods with beautiful grain and color combined with hardness are desired; and hence the popularity of mahogany, black walnut, rosewood, ebony, and oak.

It often happens that in a given locality a wood is used

for a purpose because it is the cheapest available, but not the best. For example, hemlock is largely used in eastern states for frames of buildings; but its softness and tendency to split make it far inferior to spruce among soft woods and not to be compared with the oak, formerly much used for this purpose. White pine and spruce are often used for cheap floors, but they are as much inferior to yellow pine as this is to hard maple and oak for this purpose. Such semi-hard woods as elm, chestnut, birch, and basswood are now abundant in cheap furniture, and are often stained to imitate harder woods like oak and mahogany.

Woods like chestnut and red oak, with large wood-ducts, making the annual rings very conspicuous, are said to be "open-grained." In finishing such woods for furniture it is first necessary to use wood-fillers, which are pastes for filling the open spaces left after planing, and thus give a perfectly level surface to receive the varnish. Examine polished oak furniture and compare with an oak board which has been planed but not filled.

A wood which may be split into straight pieces parallel to the central axis of the stem is said to be "straight grained." Ash, chestnut, and hemlock are commonly so; but irregularity in thickness of annual rings and in position of the medullary rays, vascular bundles and knots makes some woods more or less "cross-grained"; that is, they tend to split obliquely and not parallel to the central axis of the stem. Many woods (such as elm, sycamore, apple) are difficult to split because their wood-fibers are crossed and interlaced. Split some pieces of boards or branches of various trees by driving a wide chisel carefully and notice the direction of the fibers of the wood.

The usefulness of boards for certain purposes depends upon the direction of sawing. Examine pieces of pine,

cypress, maple and other boards, especially where they have been subjected to wear, as in floors, and note the direction of the cut of boards which have splintered or in other ways become undesirable. The transverse section is best if a block is to be subjected to great strain, as in pavement-blocks, mallets, etc.

The decorative value of the grain of woods depends in part upon the way the logs are sawed into boards. Compare the tangential and radial sections of oak and other woods, and decide which is the most beautiful cut.*

307. Forestry. — The application of scientific principles to the management of forests is known as forestry. Such scientific management has become necessary because the use of tree stems as lumber has greatly reduced the extent of forests; and in the interest of future supply it is now desirable that forest planting and forest conservation be practiced extensively. The United States Forest Service has charge of the national forest reserves, and also encourages private work in forestry by publishing pamphlets and by giving advice. Among the best of such pamphlets now available are the "Primer of Forestry" by Pinchot, which is in two parts; Farmers' Bulletins, and many leaflets (also free) giving information as to how to plant special kinds of trees; and a pamphlet "Forestry in Nature Study." All these are issued free by the United States Department of Agriculture. Another interesting book in the same line is Roth's "First Book of Forestry."

Leaves

308. Useful Leaves of Seed-Plants. — In addition to their necessary work connected with the breathing, transpira-

* To Teachers: See § 179 and Figs. 55, 56 in the "Applied Biology," and explain the methods of ordinary and "quarter" sawing.

tion, and carbohydrate-making of all important higher plants (§ 43), leaves have a number of special uses which are of economic interest. These are food, ornamental, and medicinal values.

Celery, cabbage, onion, chard, lettuce, spinach, Brussels sprouts, rhubarb, endive, cress, and parsley are examples of vegetables grown chiefly for the food value of their leaves. The same is true of the hay and forage obtained from such plants as grasses, clovers, alfalfa, corn, and others which are edible for domesticated animals.

Among leaves that contain medicinal substances are tea, camphor, catnip, sage, mint, horehound, tansy, and many others.

The ornamental value of leaves has been carefully studied by those in charge of parks, gardens, and greenhouses; and plant breeders have succeeded in selecting a large number of varieties of plants whose value is due to their leaves having peculiar shapes, beautiful arrangement, or striking colors. Many plants grown in homes or in greenhouses are good illustrations in this line; *e.g.*, compare colors and forms of leaves of varieties of coleus, geraniums, or begonias.

Flowers

309. Useful Flowers. — In addition to their necessary work in the formation of seeds, some flowers are of special value to man in the following ways. The flowers of cauliflower and French artichoke are important as edible vegetables. Many flowers contain the same medicinal substances as the leaves and both are collected at the same time for the purpose of making medicines. From certain flowers (*e.g.*, rose, violet, heliotrope) well-known perfumes are extracted. Many flowers, especially of buckwheat, melilotus, clovers,

and fruit trees, are useful as sources of honey which is collected by the domesticated honey-bees.

Most important of the values of flowers is their ever-popular use for ornamental purposes. This use is increasing rapidly, probably because people are learning more to appreciate beauty in nature. The very fact that millions of dollars are spent each year in growing many kinds of plants for the sake of their flowers is sure proof that flowers are regarded as useful by thousands of people. School-gardens, nature-study, and biology in the schools are doing much to increase the use of flowers for ornamental purposes. It will interest many students who have never examined a seedsman's catalogue to look over the pages devoted to flowers.

One of the most interesting facts is that under cultivation so many remarkable flowers have been developed. This has been done by preserving for propagation any plants which chance to develop unusual flowers. For example, California poppies are naturally yellow, but some years ago a horticulturist found a plant with crimson flowers, and now there is for sale plenty of seed of the crimson-flowered variety. In the same way the plant breeders have obtained the numerous varieties of flowers catalogued by seedsmen. Perhaps the most wonderful are the " double " ones, in which the petals have become very numerous and the stamens and pistils have largely or entirely disappeared. Many varieties of cultivated roses and chrysanthemums are " double." It is obviously impossible to raise completely " double " flowers from seeds, for without stamens and pistils they would be seedless. Such varieties must be propagated from cuttings.

Fruits

310. Useful Fruits. — The word fruit is popularly applied to the edible products of certain flowers, such as apples,

pears, berries; but in botany fruit includes all the structures, usually containing seeds, which develop from flowers, chiefly from the ovary. Thus a bean pod, a walnut with its hull, a chestnut with its bur, and a tomato, are fruits in the botanical sense.

Many fruits are useful for the seeds that they contain, but these have been referred to under seeds. There is a long list of edible fruits — such as apple, pear, quince, cherry, plum, peach, mulberry, apricot, nuts, berries, fig, pods of bean and pea, orange, lemon, banana, date, pineapple, grape, egg-plant, garden pepper, squash, pumpkin, melon, and cucumber. From some fruits medicinal substances are obtained; *e.g.*, opium and morphine from the poppy. Various bright-colored fruits were once used for dyeing, but the anilin dyes have largely taken their place. Descriptions of various types of fruits are given in §§ 212–217 of the "Applied Biology."

II. ANIMALS OF ECONOMIC IMPORTANCE

311. Microscopic Animal Parasites of Domesticated Animals. — A protozoan (§115) parasite similar to that which causes sleeping sickness in humans (§259), and injected by a similar fly, causes the disease of horses, mules, and oxen called "nagana" by the Africans, and by them correctly charged to the tsetse-fly. Those who have read the "Travels" of Livingston and other African explorers will recall how their journeys were so often delayed by death of their oxen. The disease also caused much trouble among horses during the South African war a few years ago. The fly does not develop the parasite, as mosquitoes do in the case of the malarial organism, but simply transmits the parasites from diseased to healthy animals. It is believed that the blood of some large game animals may infect the flies.

The surra disease, which destroys large numbers of horses, camels, and cattle in India and the Philippines, is due to a similar parasite transmitted by bites of flies.

Destructive diseases, caused by protozoan parasites which are introduced into the blood by the bites of ticks, affect cattle, dogs, horses, and sheep. The parasites enter the red blood-cells. Texas fever is one form of cattle disease, and it has caused enormous financial losses to stockmen in the United States.

A common disease of the liver in rabbits, diseases which seriously affect fish, the silkworm disease made famous by Pasteur's studies, — these are other cases in which parasitic one-celled animals have great economic importance.

312. Useful Protozoa. — The emphasis upon certain protozoans as causes of disease tends to leave the false impression that all protozoa are harmful, or at least useless.

A large number of common protozoans are important in the food-supply of somewhat larger animals, these in turn of still larger animals, and so on to aquatic animals such as fishes.

Thus even the minute bacteria eaten by some protozoans may indirectly, through a series of animals of increasing size, finally come to be of use in the food-supply of man himself.

Many of the protozoans are important as scavengers, assisting bacteria in breaking up dead organic bodies and preparing the organic material for use again in the cycle of organic matter. For example, a protozoan may eat some particles from the body of a dead animal or plant, build these particles into its own protoplasm, which may later serve as protein food for some larger animal; or these particles may soon be oxidized to excretions which may serve as materials for food of plants.

Another example of the usefulness of protozoans is that a

large amount of chalk in the great deposits in England and elsewhere is composed of the shells of certain protozoans. In some places these shells are very abundant in the mud of the ocean bottom.

313. Useful Sponge-Animals. — The simplest in structure and therefore the lowest animals whose bodies are composed of many cells are the sponge-animals, so called because their skeletons are the sponges of commerce. Most of them are marine animals, but certain species of no commercial importance live in fresh water. Of the marine species, some secrete skeletons of the horny material found in the sponges sold in stores; but some have skeletons of glassy fibers and some are calcareous. The glass sponges are collected and sold as curios, while the calcareous sponges are of interest to zoölogists because they represent the simplest type of sponge structure. One who wishes to understand how the cells of the sponge-animals form the complicated mass of fibers which we call sponges should begin with study of some of the simple sponges, as outlined in § 281 in the "Applied Biology," or any high-school textbook of zoölogy. The sponge-animals belong to the group Porifera (§ 87).

314. Coral-Animals and their Allies. — The sponge-animals are the simplest of the many-celled animals; and next above them are the coral-animals and their near relatives of the group Cœlenterata (cœlenterates). Perhaps the coral-animals and the jelly-fishes are the best known members of the group. We have already studied the Hydra, because it well illustrated certain points of physiology. The great majority of the cœlenterates are not of economic interest; but they are very attractive to students of zoölogy in the last years of the high-school course or in college, because they have many remarkable structures and life-histories.

Most important to man of all the allies of Hydra (§ 116),

are the animals whose skeletons form a large part of many coral islands. (Look in a textbook of geography for a list of coral islands.) Sea-anemones resemble coral-animals in structure, but do not form skeletons.

(*D*) Specimens of sea-anemones should be exhibited, and if some are available for making transverse and longitudinal sections, follow the description in § 129 of the "Applied Biology."

FIG. 85. Common sea-anemone consisting of a cylindrical body with a crown of numerous small tentacles surrounding the mouth. (*After Emerton.*)

Formation of Coral Skeletons. — On every piece of coral which has not been corroded by water, there may be seen numerous cup-like depressions, each with many radial partitions. In each of these cups there was once located a coral-animal, or coral-polyp, which secreted the cup. Imagine a sea-anemone able to form a calcareous skeleton around itself, and then you can understand the relation of a coral-animal to its surrounding cup (Fig. 86).

The fact that a piece of coral shows may cups is explained by the multiplication of individuals by budding. A coral animal which develops from a fertilized egg-cell settles down on a rock or on skeletons of preëxisting corals and begins to secrete a skeleton around itself. Buds are formed, which do not become detached as in Hydra, and these begin to secrete skeletons. The final result of oft-repeated budding is a complicated calcareous mass, in tree-like or hemispherical

form, with numerous cups representing the number of polyps which took part in the formation.

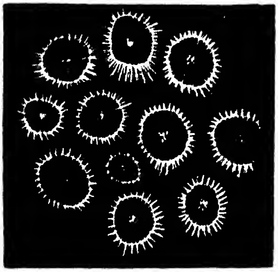

FIG. 86. A piece of coral showing cups formed by eleven individual polyps. (*From Dana.*)

The sea-fans and sea-plumes are coral skeletons formed in another way. Their outer surfaces are calcareous, and their central axis is composed of a horny material. This is black in many species, but red in the case of the precious coral from the Mediterranean, which is used in jewelry.

One species of coral-animal is found in Long Island Sound, but most of them require warmer waters. They can live at any depth down to about 300 feet, but are seldom found below 120 feet. They must have clean and undiluted sea-water. Most commonly the young animals developed from eggs attach themselves to favorable sea-bottom near land, and form fringing reefs of coral rock near the shore, or barrier reefs when a navigable channel is eroded between the reef and the shore. The formation of an atoll, a peculiar coral island in ring form and inclosing a body of water, may begin as a fringing or barrier reef around a volcanic island which later subsides or is eroded away while the deposits of coral rock continue accumulating. Or a small group of cor-

FIG. 87. A colony of coral-animals whose supporting "skeleton" (black in figure) contains the red coral of commerce. (*After Lacaze-Duthiers.*)

als may become established on the sea-bottom at a favorable depth, and as the colony grows outwards, the animals in the center are killed by coral-sand washed over them by the waves. Erosion takes place rapidly when there are no living coral-animals to keep adding to the coral rock; and so the central rock might be worn away, leaving a ring of living animals continually adding new coral rock to the outside.

315. Parasitic Worms in Domesticated Animals. — Flat worms, like the tape-worms, and round worms, like the trichina (§ 264), are parasitic in our common domesticated animals and interfere with their health. The tape-worms may occur either as the larval stage of the species which as an adult lives in the human intestine (§ 263), or the adult worm of certain species may live in the animal's intestine. For example, the tape-worms found in the intestines of dogs are believed to have their larval stage in the fleas that live on the skin of the dogs.

One of the destructive diseases of sheep is caused by a worm known as liver-fluke, which lives in the bile-ducts. It is a flat worm about one inch long and one-fourth inch broad, with two suckers for attachment. The fluke's eggs escape into the sheep's intestine through the bile-duct, and after being discharged from the intestine, each egg develops into a larva covered with cilia. This larva swims, and if it reaches a pond-snail, bores into it and becomes an elongated sac. Inside this sac are formed many new larvæ, and inside each of these larvæ are formed many more. Thus one larva entering a snail produces a large number of larvæ; and each one of these may leave the snail, become encysted on grass, and if eaten by a sheep, will enter the bile-duct and develop into a liver-fluke. When once a damp pasture along a given stream has become infested with larvæ of liver-flukes, the

only way to avoid infecting sheep is to keep them away from that stream for a number of years. Ultimately the fluke larvæ would disappear from a pasture if there were no sheep in which the parasites could complete the life-history.

Many species of round worms are parasitic in domesticated animals. Some of them live in the alimentary canal, others in blood-vessels, respiratory organs, kidneys, and elsewhere. Horses and cattle are believed to get the young worms of certain species from stagnant water; and this suggests the importance of pure water for domesticated animals. The so-called "gapes" of young poultry is caused by a round worm which fastens itself in the trachea.

316. The Earthworm. — This common worm, also known as "fishing worm," deserves more than the brief attention which our time will allow. It lives in moist soil which contains decaying organic matter, crawls out at night to feed, or when its burrows are flooded with water. It eats the soil through which it burrows, and its digestive juices dissolve bacteria, leaf-mold, and other organic matter contained in the soil. The indigestible soil is discharged and forms the "castings" which are abundant on the surface of soil where the earthworms live. Darwin found places where he estimated that worms brought more than 35,000 pounds of soil per acre to the surface in a year. This continual working of soil by worms is regarded as of great agricultural value.

General External Structure. — (*L*) Notice a living worm as it moves, which it does by successively elongating and shortening its body. Determine anterior, posterior, dorsal, and ventral. Compare the color on the dorsal and ventral surfaces. Is the animal bilaterally symmetrical? Estimate the number of segments or rings in the body. Locate the mouth and anus. Notice the glistening surface of the skin due to a cuticle. About one-third or one-quarter the body length from anterior end, there is on adult worms in the spring a swollen region, the girdle. It secretes a

cocoon in which the eggs are laid. Four double rows of small bristles (setæ), which aid the worm in locomotion, may be located by pulling a preserved specimen between a thumb and a finger, and by using a hand-lens.

The dorsal and ventral blood-vessels may be easily seen in a living animal. Select a light-colored worm, place on a moist glass plate, and then lay another piece of moist glass on top of the worm so as to compress the body slightly.

Internal Organs. — (*D* optional) The teacher should point out on preserved earthworms, which have been cut open along the dorsal side and pinned out on a narrow board, the systems of organs as described in the "Applied Biology," § 302.

317. Economic Importance of Crustacea. — The most valuable of the larger crustacea is the North American lobster, which lives on the ocean bottom within fifty miles of the shore along our North Atlantic Coast, and the Norway species, which is supplied to European markets. The large size and the peculiar qualities of lobster flesh have led to such a market demand that there has been excessive catching in recent years. The market value of the lobsters caught each year is estimated to be many millions of dollars. In recent years it has become evident that steps must be taken to prevent extinction of the American lobster. Accordingly, the United States Bureau of Fisheries has engaged extensively in hatching lobster eggs, and several states are enforcing laws which prohibit taking short lobsters (under six inches long in some states, nine in others) and females with eggs attached to the abdominal appendages. The advantage in hatching lobster eggs artificially is due to the fact that fishes and other enemies usually destroy a very large number of eggs or young larvæ, but in the hatching troughs they can be protected until several days old and better able to care for themselves. The eggs are collected by brushing them from the abdominal appendages of the females. A

female a foot long may have over ten thousand eggs, and giant specimens over eighteen inches long have been found with more than 150,000 eggs.

Next to the lobster, the crabs are important as articles of human food. The blue crab is the favorite. Spider crabs and fiddler crabs are not used as food. The "soft-shelled" crabs of our markets are simply individuals which have recently shed their shells (*i.e.*, molted), and the new shell has not had time to harden by deposit of lime salts.

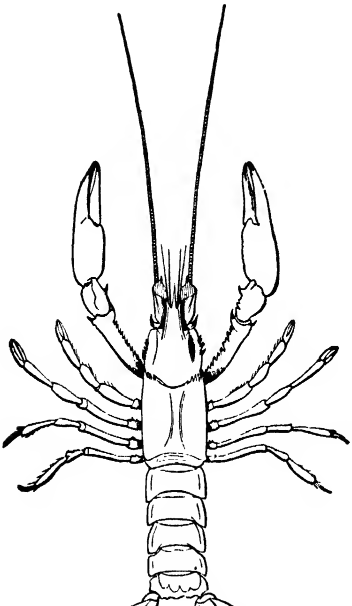

Fig. 88. Blind crayfish from Mammoth Cave. (*From Packard.*)

Crayfishes have long been used for food in France and elsewhere on the continent of Europe. More than thirty years ago Huxley wrote that Paris paid over $80,000 per year for crayfishes. In the United States they are found in special markets of the large cities. Half a million are shipped annually from the Potomac River. Oregon ships more than 100,000 pounds. The demand is increasing, and it will probably pay to have crayfish farms on which to raise them for market. Land too wet for agriculture might be so used.

The shrimps seen in New York markets usually come from the Pacific Coast, and the trade in them is worth many hun-

dred thousand dollars annually. Only the abdomens are commonly sold in the markets, and the bright red color is due to their having been boiled.

(*L*) If time allows, some brief laboratory studies of crayfish or lobster and crabs should be introduced at this time.

318. Economic Relations of Spiders and their Allies.* — In the lessons on animals that affect human health it is stated that the fear which most people have concerning spider bites is unfounded. Instead of being dangerous to man, the spiders are useful as destroyers of insects, which they catch by means of their webs. The silk of the webs may be made into cloth finer than that from the silkworm, but it is much more difficult to rear spiders and collect the silk from their spinning organs (spinnerets). The spider's silk is so delicate that it has often been used for the "cross-hairs" which mark the centers of telescopes.

FIG. 89. A common spider. Four pairs of legs, while insects have three. Abdomen much larger than head-thorax. (*From Parker and Haswell.*)

The best known relatives of the spiders are the scorpions. Concerning their bites, see § 265. Like the spiders, they are destroyers of insects.

The mites and ticks belong to one of the groups of spider-like animals. The itch-mite (Fig. 91) burrows in the human skin, causing itch, and another species causes "mange" in the skin of dogs. The ticks live as parasites on skins of

* The spiders are interesting animals for observation. For the general points of structure, see the "Applied Biology." The chapters on Arachnids in Davenport's "Elements of Zoölogy" and Jordan and Heath's "Animal Forms" should be read by students. See also "Cornell Leaflets" or Comstock's "Nature-Study."

various animals. Sheep ticks cause ill health of sheep and great financial loss to stockmen. Cattle ticks spread the germs of the destructive disease known as Texas fever. In Africa there is a human disease known as "tick-fever." It is probable that other disease germs are spread by these skin parasites, and hence all of them which bite man or the useful birds and mammals should be regarded as injurious animals.

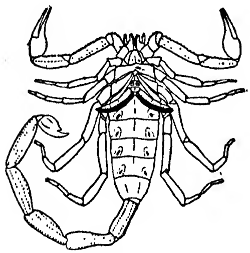

FIG. 90. Scorpion. Four pairs of legs, a pair of pincers, and one of mandibles. Sting at end of "tail." Four pairs of breathing pores on larger part of the abdomen. (*From Kingsley.*)

319. Useful Insects.—Honey-bees and silkworms are the only truly domesticated insects. A few others are directly useful for their products, —"Spanish flies" (used in medicine), cochineal bug (cultivated on cactus for the dyes cochineal and carmine which their dried bodies yield), and the lac-insect (which produces the valuable shellac used in varnishes). Some natives of Africa, Australia, and Mexico eat certain insects.

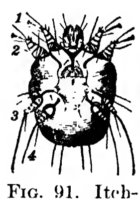

FIG. 91. Itch-mite, a skin parasite. Note four pairs of legs.

As *agents in cross-pollination* of flowers, insects as a group are worth more than what they destroy; but it happens that many of the very destructive insects do not visit and pollinate flowers. Many of our most useful plants depend upon pollination by insects, *e.g.*, clover, alfalfa, fruit trees, and most vegetables. The Smyrna fig is now successfully cultivated in California because an insect imported from Algeria pollinates the flowers.

Some insects are vaulable as *destroyers of injurious insects.* Numerous insects have their insect enemies, some predatory

and some parasitic. As an example of predatory insects may be mentioned the history of the fluted scale-bug which once threatened to destroy the orange groves of California. The scale originally came from Australia, and there the entomologists of the United States Department of Agriculture found a natural enemy in a species of lady-bird beetles. Some of these beetles were imported to California and in a few years practically exterminated this species of scale-bug. Specimens of the beetles sent later to other countries have been successful in ridding orange and lemon trees of the destructive scale-bug. This is one example of the usefulness of a predatory insect. Many with similar habits are constantly keeping harmful insects in check.

Parasitic insects are important checks on injurious insects. A large number of species of insects belonging to the Diptera and Hymenoptera are parasitic during their larval stage. The caterpillars of many moths and butterflies are frequently parasitized by larvæ of certain flies. The ichneumons (Hymenoptera), of which more than ten thousand species are named, are famous parasites. Some of these insects have ovipositors three and four inches long and are able to bore deeply into trees in order to lay their eggs in the larvæ of another insect. "Tomato-worms" (larvæ of hawk-moth) and similar moth larvæ are often seen with their skins covered with small white cocoons. The parasitic larvæ live inside the moth larvæ and crawl out to the surface of the skin when ready to pupate. The result in most cases is the death of the parasitized caterpillars.

The above are simply illustrative examples chosen from the thousands of cases in which insect parasites destroy other insects. In all such cases where the insect host is harmful the parasite is beneficial.

Finally, it must be mentioned that insects are *useful as*

foods for numerous species of birds. True, it is often stated that the birds are useful as destroyers of insects; but intelligent people are beginning to recognize that many birds would be useful and well worth supporting for æsthetic purposes even if there were no injurious insects to be destroyed. Aside, then, from the great outbreaks of certain insects, a limited number of them are desirable as food for interesting birds.

Also, it should be mentioned that many fishes eat large quantities of insects, both adults and larvæ. This is why imitation insects are used as bait by anglers.

320. Injurious Insects. — Those insects which injure or destroy useful plants and animals, or organic products (*e.g.*, foods and textiles) which are of value to man, or which injure man himself (as by infecting with malaria), are conveniently grouped as injurious insects. The truth is that a very large proportion of insect species are injurious, but usually they do not attract attention unless they become excessively numerous, or unless man develops a special interest in an animal or plant which they injure. For example, probably more than eight hundred species of insects attack oak trees; but it is rare that enough appear on any one tree to do any noticeable damage, and as long as there are plenty of oak trees no one cares how many kinds of insects live on them.

A few *statistical estimates* will give some idea of the damage which a single species of insect can do. The grasshoppers (Rocky Mountain locusts) destroyed crops to the value of $200,000,000 in Iowa, Missouri, Kansas, and Nebraska in four years, 1874–1877. Enormous damage has been done by chinch-bug on cereal plants, by Hessian fly on wheat, by scale-bug on fruit trees, by gypsy moth on forest and fruit trees, by cotton-boll weevil, and by numerous others which do great but less damage than those mentioned. Famous

entomologists have estimated that insects damage farm crops in United States annually to the extent of $300,000,000. Insect damage to valuable forest trees is on good authority estimated at $100,000,000, yearly. Add to these figures the enormous loss of animals through disease caused directly or indirectly by insects; the destruction of clothing, foods, and other useful articles; the value of the working time and expense of treatment of people who are ill through diseases caused by insects, and the total annual cost of insect damage in this country is probably more than the combined cost of the army and navy and the public-school system. Such general estimates suggest the immensity of the problem of dealing with the injurious insects.

And yet such statistics must not be taken as a declaration of war against insects indiscriminately. They simply mean that efforts must be made to hold in check the ones which are noticeably harmful. The ordinary insects which one meets during a long walk in the country are not likely to appear in such numbers or to develop such new habits as to be of special economic interest. Hence there is no reason why we should destroy them. On the contrary, this old world is of greater interest because of their existence. As an illustration, katydids and crickets do eat some leaves of grass and other plants, but to many a person who is interested in nature-study a mid-summer night's chorus by these insects is worth far more than the trivial damage they do.

The Control of Injurious Insects. — The investigations by entomologists in the past fifty years have made great progress towards controlling injurious insects. Knowledge of habits and life-histories has made it possible to prevent destruction of crops. Here are a few from hundreds of examples recorded in the large works on economic entomology: The discovery that the fruit-moth (codling moth) lays its

eggs in the calyx of apple flowers after the petals have fallen suggested the desirability of spraying the trees with arsenical poisons before the larvæ hatch and burrow into the fruit. Grasshoppers lay their eggs a few inches below the surface of the soil, and hence shallow plowing in the autumn will expose the eggs to the winter storms. The scale-bugs and plant-lice live by sucking sap from plants, and hence poisons like arsenicals cannot reach their stomachs, and the logical conclusion is that they ought to be sprayed with lime-sulphur, or petroleum, which kill by contact. These cases are simply illustrations of the fact that all the satisfactory methods of dealing with injurious insects are based upon careful biological study of the species in question.

321. Economic Relations of Starfish. — This animal is a member of the group of echinoderms, which contains the starfishes, sea-urchins, crinoids (sea-lilies or feather stars), and sea-cucumbers. Most of these are of interest only in zoölogy, and they are attractive to advanced students because they are not closely related to any other groups of animals and have many striking peculiarities. Certain large sea-cucumbers of the Pacific are dried and form an important article of commerce with the Chinese, who consider them a delicacy. The only other echinoderms of marked economic interest are certain species of starfishes which feed on oysters and clams, and are often so numerous as to cause great loss to owners of oyster-beds. Since a starfish has no jaws and an extremely small mouth, it is evident that only by some unusual method of feeding could it eat an oyster. This is accomplished as follows: The starfish stomach is a large, thin-walled sac which can be everted through the small mouth, much as one might turn a glove-finger inside out. A starfish fastens its suckers on an oyster, and then the stomach covers the edges of the oyster's shell,

with the result that the circulation of water inside the oyster's shell is stopped and the animal is killed by suffocation. The oyster shell then gapes open, the starfish's stomach pours in its digestive secretion, the tissues of the oyster are dissolved (digested) while in its own shell, and then the digested substances are absorbed by the starfish. Finally, the starfish withdraws its stomach into its own body and leaves the empty shell of the oyster.

Against such a remarkable enemy an oyster or clam is completely helpless, for the hard shell which protects against enemies that feed with jaws is of little avail against the starfishes, which are the only animals able to evert their stomachs for the purpose of surrounding and digesting food too large to be taken into the mouth.

Owners of oyster-beds now make systematic efforts to destroy starfishes; and steam dredges are used to bring both oysters and starfishes to the surfaces. Formerly, the oyster fishermen used to break the arms from starfishes and throw them back into the sea; but the discovery that starfishes have the ability to regrow or *regenerate*, and that each of many pieces may soon form a perfect starfish, showed that breaking them into pieces simply multiplied them. Now, when starfishes are caught by oyster-dredges, they are killed instantly in boiling water, or they are left on dry land where they die quickly.

(*D*) Exhibit specimens of various echinoderms for the sake of general acquaintance. Also use illustrations in books of zoölogy.

322. Economic Relations of Mollusks. — The group of the shell-animals or mollusks (Molluska) includes such familiar forms as clams, oysters, snails, garden slugs, "sea-shells," and the rarer chitons, squid, nautilus, octopus, and others. If time allows for careful study of some of these,

see textbooks of elementary zoölogy or §§ 336–342 in the "Applied Biology."

The value of the oyster industry in America and in Europe is enormous. Studies by zoölogists connected with government laboratories have vastly improved methods of propagating, and have made it possible to raise oysters where they do not naturally grow. Oyster-beds are now regularly leased by states to oystermen, and oysters are artificially "planted." In many places it is necessary to rake the sea-bottom with steam dredges annually in order to bring the oysters to the surface and free them from the destructive starfishes. The egg-laying months are May to August, and the popular saying that oysters are not edible except in the months with the letter "r" in their names, *i.e.*, September to April inclusive, is connected with the fact that in the months without "r" (the summer months) the animals are likely to be filled with eggs. The oysters are the most valuable mollusks, and the business of raising oysters is worth millions of dollars a year. From Chesapeake Bay alone more than twenty-five million bushels of oysters are marketed annually.

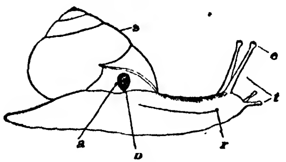

FIG. 92. Diagram of a land-snail (Helix). *s*, shell; *a*, anus; *b*, breathing pore opening into the "lung"; *r*, opening of reproductive organs; *t*, four tentacles; *e*, eyes at end of longer tentacles. (*From Parker and Haswell.*)

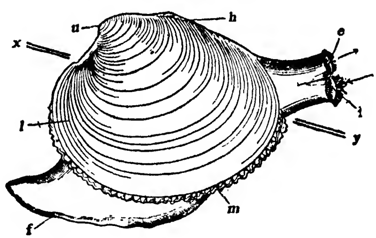

FIG. 93. A marine clam. All below the line *x–y* is usually imbedded in the sand. *h*, hinge of the shell; *u*, umbo; *l*, parallel lines of growth of the shell; *m*, edge of mantle; *f*, foot; *e*, *i*, exhalant and inhalant siphons, the arrows indicating the direction of currents of water. (*From Verrill.*)

The marine clams (Fig. 93) and scallops are of great importance as food, and attempts are now being made to cultivate them. Unless this becomes commercially successful, the natural supply will soon be exhausted. Investigations are being made under the auspices of the United States Bureau of Fisheries and of certain state experiment stations; and these scientific institutions deserve the necessary financial support by legislative bodies.

Certain large land-snails (Fig. 92) have long been esteemed as delicacies. There were snail-gardens in Roman times, but now the snails are widespread pests in vineyards and gardens of Europe. Many are collected and shipped to American dealers in food delicacies.

Preparations from snails were once used for coughs, consumption, malaria, asthma, dropsy, and almost all other diseases. In some rural regions of England people still believe that snails are of medicinal value.

Numerous marine snails (gasteropods) are used as food in various parts of the world. Squids (Fig. 94) and cuttle-fishes are eaten by poor people in some countries.

Sepia or India ink has been obtained from cuttle-fishes. The famous Tyrian purple, once used for coloring royal robes, came from another mollusk.

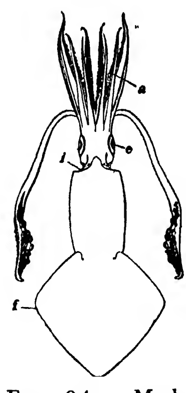

FIG. 94. Male squid. *a*, arms — two long ones in male; *e*, eye; *i*, opening to siphon; *f*, fin. (*After Verrill.*)

Shells of mollusks are of great ornamental value. They have long been sought by conchologists (collectors of shells), and more than $100 has been paid for a single rare specimen.

Natives of the islands in the Pacific Ocean use shells for a great variety of purposes, ornamental and useful. In some

barbaric tribes of Central Africa shells still pass as money, and the "money cowry" is the standard currency. The North American Indians once cut cylindrical beads from the purple spots on shells of the hard-shelled clam (Venus), and this was at least one kind of "wampum" mentioned in early colonial history of the United States.

Civilized men make extensive use of shells. Some are used for inlaying and for other ornamental work. Vast quantities are used for pearl buttons. Pearls of great value are each year collected from clams of various species. In North America many pearls are found in the rivers of the Mississippi system and in Lower California.

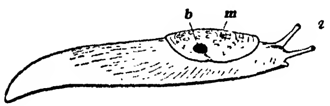

Fig. 95. Garden slug (Limax). *t*, tentacles; *m*, mantle covering rudimentary shell; *b*, breathing pore. (*From Morse.*)

Garden slugs (Fig. 95) are like land-snails with degenerate shells. They are sometimes so abundant in gardens that their feeding causes great damage.

(*L* or *D*) Specimens of the various types of mollusks should be examined at least for the purpose of obtaining a general acquaintance; and if time permits, it is advisable to make a laboratory study of a clam and snail according to §§ 337 and 339 in the "Applied Biology."

323. Economic Value of Fishes. — A few examples of fishes which are important in the human food-supply will suggest the enormous total value of this group of animals.

External Structure of a Fish. — (*L*) Any available fish from the market should be examined. Note the two pairs of lateral fins; and the dorsal and ventral fins on the median line. Compare several species of fishes, or pictures of them, as to the arrangement of the fins; and especially note that the posterior pair of fins is in some fishes near the anterior pair. Note arrangement of scales.

Examine the mouth and gills.

Observe (1) the movements of the body and fins, and (2) the mouth and gills of living fishes in an aquarium.

Salmon worth more than $13,000,000 are annually caught on the Pacific Coast of North America, nearly one-third of these from Puget Sound and Columbia River. The average weight of a full-grown salmon of the Columbia River species is over twenty pounds, and individuals have weighed 100 pounds.

Herrings are probably the most valuable food fishes in the world. Huxley estimated that three billion, each averaging half a pound in weight, are caught in the North Sea and Atlantic annually; and this is now too low an estimate. They swim in enormous groups or "shoals" which sometimes extend over half a dozen square miles. "Sardines" from Maine are simply small herrings, but the true European sardines belong to another species.

The codfish is one of the most important North American fishes. About 7000 men are engaged in the fishery, and the annual catch is in some years near 100,000,000 pounds and worth to the fishermen about $2,000,000. The cods live in deep water (20 to 100 fathoms), and are captured only with baited hooks and lines. A cod over six feet long and weighing over 200 pounds was once taken; but from 12 to 40 pounds are the usual weights.

Next to the Columbia salmon and the cod, the shad is the most important fish caught in the waters of North America. It is captured in the spring when it ascends rivers to spawn. The annual catch is about 14,000,000 fish, weight 50,000,000 pounds, and worth more than $1,600,000. The fact that the shad is taken only at the spawning season would long ago have made the fisheries unprofitable if the United States Fish Commission had not engaged in artificial propagation.

More than 200,000,000 young shad are annually "planted" in the rivers of the Atlantic Coast. They have been introduced since 1871 on the Pacific Coast, where they do not naturally occur; and have now become abundant in the markets of the west-coast cities. No better proof could be desired as to the value of the work of the government in artificial propagation of fishes. And this is only one of many fishes which has been widely distributed and made more abundant as the result of science applied by the experts on fish culture.

The three most valuable North American fishes have been selected to illustrate this discussion of economic value; but there are many others worth tens of thousands of dollars annually. The fact is that we have scarcely begun to learn the real value of fishes as a source of meat food. There are hundreds of rivers, lakes, and ponds which might be stocked with fish of selected species and made to produce an abundance of good food, the fish, moreover, destroying numerous larvæ of the dreaded mosquitoes. It is certain that the successful methods of artificial hatching and distribution which have been discovered by experts in the government service will ultimately make many useless bodies of water profitable to their owners.

The student who is interested in fishes should refer to Jordan and Evermann's "American Food and Game Fishes."

324. Economic Relations of Amphibians. — The class Amphibia includes the frogs, toads, and the tailed forms which are popularly called newts, salamanders, mud-puppies (Necturus), water-dogs, and mud-eels. Some of these are often mistaken for lizards; but lizards (*e.g.*, chameleons) are reptiles with scaly skin, while the common amphibians have smooth skin like that of the frog. Some of the tailed am-

phibians have gills in the adult state, and live in water. Those without gills respire by means of the skin when in water, and by lungs and moist skin when on land. It is well known that frogs' legs are eaten; and it has proved profitable to catch frogs for the market. In fact, the annual hunting of nearly $50,000 worth of wild frogs will soon exterminate them unless "frog-farms" are more extensively developed in the near future. But the chief value of our common amphibians is that they destroy thousands of insects. The common toad is a valuable inhabitant of gardens. See the bulletin on the American toad which is published (free) by the United States Department of Agriculture, and also see a chapter in Hodge's "Nature Study and Life." We ought to have laws protecting toads as well as birds, but until we get such laws we must depend upon the good sense and fair play of intelligent people who are informed concerning the value of toads. Frogs are likewise useful as destroyers of insects, but have not attracted so much attention as the toad, which is able to go far from bodies of water and can be kept in gardens.

The newts and other species of tailed amphibia which spend much time on land are probably useful destroyers of insects.

Myths concerning Toads. — The skin secretion in some toads is disagreeable or even poisonous to their enemies, but produces no serious effect on human skin. Warts on small boys' hands are not caused by handling toads. The truth is that warts may be caused by slight scratches which allow dirt to get into the skin. Moreover, killing a toad will not "cause your father's cow to give bloody milk," for a moment's serious thought shows us the absurdity of the folklore that there is such a relation between cows and toads. Both the wart and the milk legends are absolutely unscien-

tific. There are numerous other absurd beliefs concerning common animals, and one who has studied biology will always demand proof or the authority of some modern scientific book before accepting them.

325. Economic Relations of Reptiles. — There are four types of reptiles: lizards, turtles, snakes, and alligators. Most lizards are harmless, and may be useful as destroyers of insects. Iguanas and other large species are hunted for their flesh. Brilliantly colored lizards are often kept as pets; they should be fed insects, and not starved on sugar and water. (Why?)

Many species of turtle are valuable as human food. Terrapin turtles are now so very high in price that "terrapin-farms" are profitable. Beautiful tortoise shells, which are plates or scales from the back of a tortoise, are made into combs and ornamental articles.

Poisonous snakes have been mentioned in § 266. Most American species are not directly harmful to man, but some are really useful in that they destroy such rodents as rats and mice. However, those that eat rodents are also fond of young birds and eggs, and are indirectly injurious because most birds of the kinds killed by the snakes are useful and should be protected. Some of the non-poisonous snakes prefer frogs and toads, which are useful as destroyers of insects. There is so much variation in the food of common snakes that one should consult Ditmar's "Reptile Book" before deciding that any given species is indirectly harmful because it kills useful animals.

Alligators are valuable for their hides. In fifteen years (1880–1895) 2,500,000 were killed in Florida. The eggs are edible, and many people hunt eggs during the proper season. Curio dealers sell to tourists large numbers of young alligators, which almost always die of starvation. The species

will soon be extinct except in the most inaccessible swamps.

326. Economic Relations of Birds. — In several ways birds are of practical or economic interest to man. Probably most important is the use of certain species for food. Some of these (ducks, geese, chickens, pigeons, turkeys, Guinea fowls, and pheasants) have domesticated varieties or breeds which for meat and eggs are more valuable than the original wild species. Numerous wild species of ducks, geese, grouse, pheasants, quails, turkey, and many so-called "game birds" are useful as food, but most of them have been hunted so persistently that they are no longer abundant enough to furnish a very important part of civilized man's food-supply.

Feathers of many birds are used for ornamental purposes, and those of others for pillows. Ducks, geese, and ostriches are the most important of the domesticated birds which are kept for the feathers that are plucked before the birds are ready to shed or molt them naturally. The feathers of chickens and some birds are saved when the birds are dressed for the market. The most beautiful of ornamental feathers are obtained from wild birds such as certain herons (egrets), paradise birds, parrots, etc., which are usually killed in order to get the feathers. The milliners' demand for these is rapidly leading to extinction of many species of beautiful birds. In the case of the snowy heron or egret, from which aigrettes are obtained, the birds are always killed when they have young nestlings and these inevitably starve to death. This is the reason why sensitive women who know the story of the egret will not wear aigrettes and why the societies for the protection of wild birds have been so active in trying to stop the sale of the plumes. In the cases of many other beautiful feathers used for millinery, most awful cruelties are practiced by the hunters who collect them for market.

The Audubon Societies, which are interested in bird study and protection, have for many years been working for legislation which will stop the commercial handling of feathers of many kinds of wild birds, for this is the only practicable way of discouraging the hunters.

Besides the direct usefulness of birds for food and feathers, many of the wild birds are of value because they eat injurious insects and weed seeds. All species of sparrows and finches, juncos, mourning doves, quails, pigeons, and grouse are some of the birds known to feed largely on seeds of useless plants and weeds. However, there are no exclusively vegetarian birds. A large proportion of the food of most common birds consists of eggs, larvæ, or adult insects, many of which are injurious. Thus indirectly such birds are useful to man. Flycatchers and swallows are the best insect hunters; but woodpeckers, cat-birds, robins, blackbirds, crows, blue-jays, cuckoos, some hawks, warblers, chickadees, various thrushes, some owls, and many other birds are credited with making at least part of their meals on injurious insects.

Many of the hawks and owls are beneficial in that they prefer mice and other rodents. Even a few field-mice cause appreciable damage to meadows and grain fields; and in many parts of Europe there are occasional plagues of the mice.

Certain birds destroy seeds, fruits, and useful plants. Some of the same birds are also destroyers of injurious insects and weed seeds. The robin is an example; sometimes it eats cherries and other small fruits, but most of the year it must get other kinds of food, and on the whole is a useful bird. Any birds that eat large seeds may destroy ripe grain in the fields, and sometimes do considerable damage. However, it is probable that the same kinds of birds destroy enough insects at other times to compensate for the damage. An exception is the case of the rice fields which are visited

by countless thousands of migrating blackbirds and rice-birds (bobolinks), and these do serious damage without being at any time of appreciable benefit to the rice planters.

The birds of prey are charged with destroying useful birds; *e.g.*, certain hawks and owls occasionally destroy poultry. However, most of these as destroyers of mice and insects more than pay for the damage, and they should not be killed indiscriminately. Cooper's hawk, the sharp-shinned hawk, the goshawk, and the great horned owl are the only ones whose attacks on useful birds may justify killing them, especially in some places where they are abundant.

There is much doubt as to whether certain kinds of birds should be protected, for the evidence for and against them is nearly equal. Examples are the crows, blackbirds, blue-jays, bobolinks (rice-birds), English sparrows, the above-named birds of prey, and many others. Local overabundance often makes it desirable to destroy some of these birds in order to reduce the numbers; but they should not be exterminated.

The relations of birds to man should not be considered entirely from the economic point of view presented in the foregoing paragraphs, for it is probable that there are more people who enjoy the birds as beautiful and interesting animals than who have a purely economic interest in them. The great majority of birds deserve protection because of the widespread interest in them as well as because they are useful to man.

References. — Farmers' Bulletin 54 and several other pamphlets on the economic relations of birds are distributed to applicants by the United States Department of Agriculture. Weed and Dearborn's "Birds in their Relation to Man" is a very readable summary of the best literature on the subject. The most popular magazine devoted to birds is "Bird-Lore" ($1 per year).

327. Economic Relations of Mammals. — No other class of animals approaches that of the mammals in economic importance. The truth of this statement will be obvious to any one who considers the vast monetary value of the common domesticated mammals — horses, cattle, sheep, pigs, goats, and dogs. Also, in some countries, camels, elephants, llamas, and reindeer are important domesticated mammals.

The domesticated species are useful in (1) the human food-supply, and (2) as beasts of burden.

Many wild mammals are also useful to man. The most valuable of these are the fur-bearers (chiefly carnivores, such as seals, foxes, mink, bears). Whales have long been hunted for the whale-bone obtained from their jaws and the sperm-oil from their "blubber." A large whale of one species may yield over $10,000 worth of whale-bone and three hundred barrels of oil. Elephants and walruses have been ruthlessly hunted for the ivory of their tusks. Sea-cows are hunted for their flesh, oil, and hides. Beavers have been nearly exterminated because of their valuable skins.

Modern methods have made it possible to utilize every particle of mammals slaughtered for human food. In addition to the meat obtained, the poorer qualities of fat are made into soap; the horns into combs; the hoofs into glue; the best hair into packing for many purposes, while the poorer grade is used in plastering walls of buildings; gelatin is made from tendons; leather from the dermis of the skin; lean scraps and blood are dried to make foods for poultry and other animals; bones are made into hundreds of useful articles and the best small pieces are ground into bone-meal for feeding poultry; and any particles of bone, blood, or flesh, not usable in other ways, are dried and pulverized to make commercial fertilizers for agricultural use.

The dog was the first domesticated animal, and it is in-

teresting to note that primitive dogs were probably chiefly kept as pets and companions, just as many of our modern dogs are to-day. The development of such uses as hunting, guarding flocks of sheep, and drawing sledges and carts seems to have come after the dog's masters began to emerge from the lowest barbarism.

Among very injurious mammals are numerous species of rodents (*e.g.*, rats, mice, gophers, prairie-dogs, certain squirrels, rabbits in Australia); some carnivores (*e.g.*, the dangerous cat-like species, the weasel-like forms, the bears and wolves); and fruit-bats.

Some mammals which are insect-eaters are indirectly beneficial. Many bats, ant-eaters, and the moles are examples; but owing to their subterranean habits the moles do much damage to roots among which they burrow in search of larvæ of insects.

References. — Concerning the injurious mammals (rodents, wolves, etc.) there are many pamphlets issued by the United States Department of Agriculture. Two of the most interesting books dealing with domesticated mammals are Shaler's "Domesticated Animals" and Wood's "Dominion of Man."

CHAPTER XII

THE REPRODUCTION OF ORGANISMS

328. Individual Life Limited. — We have already noted that all individual animals and plants grow old and die, and that reproduction or generation of new individuals (offspring) is necessary for the perpetuation of any species. For example, individual horses do not live fifty years, and it is evident that unless new individuals are reproduced by the present horses, the horse species will become extinct within fifty years. Reproduction, then, is a necessary process of developing new individual organisms for the perpetuation of species.

Within the limits set for this book there is space for describing the reproductive processes of only a few selected animals and plants. It will be most interesting and instructive to begin with some of the simplest (the one-celled) animals and plants. These probably existed on the earth before the higher organisms appeared, and their reproduction represents the simplest methods by which species can be continued by production of new individuals to take the places of their parents.

REPRODUCTION OF THE SIMPLEST ORGANISMS

329. Reproduction of One-celled Animals. — Amœba, paramecium, and all the other one-celled animals reproduce by automatic division of their bodies into two equal parts. These are young individuals able to take food and grow,

and when of full size they in turn divide. Examine Figs. 96 and 97. When food is abundant the paramecia will divide about three times in forty-eight hours, that is, one individual will divide into two, these into four, and these into eight within two days.

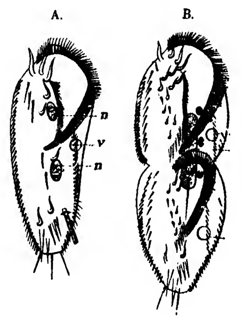

FIG. 96. Division or reproduction of a Stylonichia similar to that of Paramecium. *n*, nucleus; *v*, vacuole. (*From Hatschek.*)

It is interesting to note that in this simple form of reproduction the parent animal loses its individuality when it reproduces. Contrast this with higher forms, as the frog, which produce young, while the parent continues to live until it grows old and dies. It is evident that, barring accidents and disease, there is no chance for a paramecium or an amœba to grow old and die; for when it reaches full size, it divides into two young animals, which in turn take food, form new protoplasm, grow to the full size, and divide.

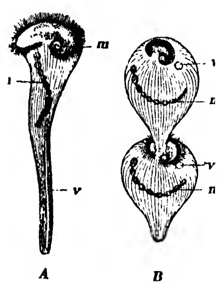

FIG. 97. Division of a Stentor (trumpet-animalcule). *n*, bead-like nucleus; *v*, vacuole. (*From Hatschek.*)

Conjugation. — Under certain conditions, paramecia reach a state in which they are unable to continue to divide. Two such individuals come into contact, and through their delicate cell-walls some of the nucleus of each one passes over to join the nucleus of the other. Then the two animals swim away independently, each soon divides, and their offspring may continue to divide for a long series of generations before this process, known as *conjugation*, again takes place. Other kinds of one-celled animals conjugate.

330. Reproduction of a One-celled Plant. — A green coating or stain which is often seen on the shaded (usually north) side of tree trunks, unpainted walls, etc., will be found upon microscopic examination to be composed of masses of one-celled plants (Pleurococcus), often arranged in groups of two, four, or more cells (Fig. 98). This grouping is the result of repeated cell-division. Each cell has protoplasm, nucleus, chlorophyll-bodies, and cell-wall. Having chlorophyll, they are able to make carbohydrates from carbon dioxide and water. Particles of dust lodged on the wood on which they grow probably supply the necessary materials which higher plants absorb from the soil. Abundance of water favors growth, and they appear a brighter green during rainy weather.

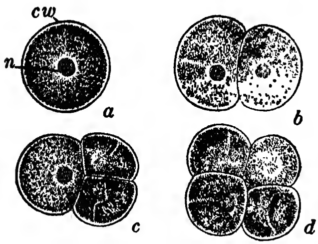

FIG. 98. Division of a one-celled plant (*a*) into two cells (*b*), three cells (*c*), four cells (*d*). (*From Sedgwick and Wilson.*)

Bacteria (§ 239) and yeast (§ 280) are also good examples of the simplest method of plant reproduction, by division.

THE SIMPLEST METHOD OF REPRODUCTION

331. Asexual Reproduction. — The one-celled animals and plants illustrate a type of reproduction in which sex is not involved. The individuals are not male or female, but they are all alike and capable of reproducing by division. There are no eggs or ovules such as we know form the new individuals of higher animals and plants. Such reproduction in which there are no eggs but in which the new individuals are formed by division of the parent individuals is known as *asexual reproduction* (meaning reproduction without sex),

while such development as that of insects and fishes from eggs and of seed-plants from ovules of flowers is *sexual reproduction.*

In most cases of sexual reproduction of animals and plants there are two parents, the female, whose ovaries produce ova or egg-cells, and the male, whose spermaries produce sperms or sperm-cells; and an egg-cell does not develop until it has been entered and fertilized by a sperm-cell. This entrance into an egg of a sperm-cell is called *fertilization.* There are some species of insects and plants able to produce egg-cells capable of developing without being fertilized.

In addition to the reproduction by division of the one-celled organisms, there are many examples of asexual reproduction among the many-celled animals and plants.

332. Asexual Reproduction in Animals. — The Hydra (§ 116) reproduces asexually as long as it has abundant food and other favorable conditions of life. A small elevation (called bud) appears on the side of a hydra and within a few days grows to form a small hydra (Fig. 53). This soon becomes detached, and lives independently. If food is abundant and a hydra is growing rapidly, it may have two or three buds developing at the same time and the young animals formed may soon reproduce by budding.

Under certain unfavorable conditions, such as lack of food, stagnation of water, etc., hydras may cease growing and budding and develop reproductive organs (ovaries and spermaries), which form egg-cells and sperm-cells. When the spermaries of a hydra are mature, the sperm-cells escape and swim freely in the water. A single ovum or egg-cell develops in an ovary, and is fertilized by the entrance of a single sperm-cell (§ 348). The fertilized egg-cell forms an embryo, and becomes surrounded by a hard shell or cyst. The protected embryo falls to the bottom

of the pond, and it may remain there for some time. Dry dust scraped from bottoms of ponds during mid-summer drought may contain embryos which will develop into hydras soon after being placed in water.

Hydras have another reproductive process which occurs only when by some accident an individual is cut into two or more pieces. The remarkable fact is that within a few days each piece will grow into a perfect hydra. This is an example of *regeneration.* Many other lower animals have the same power of forming a perfect body from a part, and some animals as complex as frogs can regenerate small parts, such as toes, if they happen to be destroyed. It should be noted that

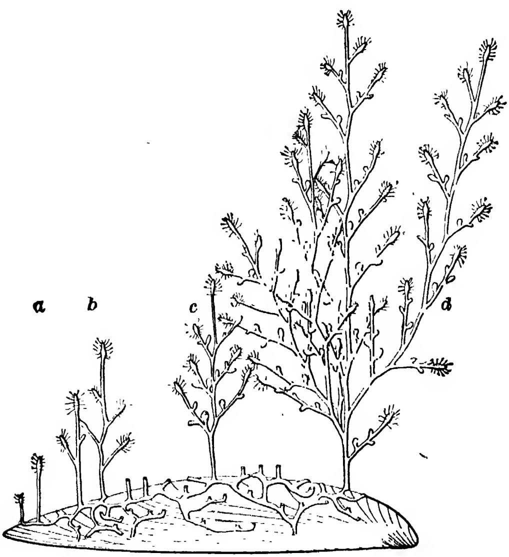

FIG. 99. Hydroids growing on a mussel shell. A tree-like group, such as *d*, is formed by repeated budding (compare *a*, *b*, *c*, *d*). A single, free-swimming larva, from one egg-cell, attached to the shell and formed the first hydroid, from which all these originated by budding. (*After Schulze.*)

regeneration is not a regular reproductive process in hydras, but provides against accidents.

The marine animals known as hydroids, which are near relatives of Hydra, form buds that do not become detached, but remain and grow into branches similar to those of a tree (Fig. 99). In this way a single hydroid developed from an egg may by repeated budding grow into a tree-like colony in which there is an hydroid individual at the end of each branch (see Fig. 99). Some of these individuals form medusæ or jellyfishes, which become detached, float in the water, and form eggs and sperms. Each fertilized egg develops into a young hydroid which attaches itself to a rock and by repeated budding forms a new hydroid colony like that represented in Fig. 99.

Most worms reproduce by fertilized eggs (*i.e.*, sexual reproduction), but some have also asexual reproduction. The marine worm represented in Fig. 100 is able to divide off new worms at its posterior end, and sometimes several such divisions may be occurring at the same time so as to form a chain of small worms. This chain finally breaks and the individuals become independent.

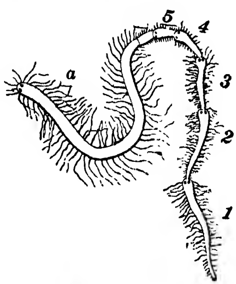

Fig. 100. A marine worm that sometimes reproduces by division (*After Milne-Edwards.*)

The complex animals such as the crustaceans, insects, spiders, snails, and vertebrates do not reproduce asexually; but only from eggs which, with few exceptions, must be fertilized in order to develop.

333. Regeneration. — Many animals are able to regrow or regenerate parts which have been cut off. If an earthworm is divided by a gardener's spade, the two parts may

grow into perfect worms. A starfish may be broken into several pieces and each will regenerate and form a perfect starfish. A hydra may be cut into many pieces and each will form a perfect hydra of small size within a few days. Such power of regeneration is common in the groups to which amœba, hydra, flat-worm, earthworm, and starfish belong. Many animals of the higher groups are able to regenerate certain organs, such as legs; but cannot form two or more complete individuals from the pieces of one animal.

Regeneration is not a regular method of reproduction, but in the case of animals like hydras, earthworms, and starfishes, it may result in multiplication of individuals whenever any accident causes division of one of these animals.

334. Asexual Reproduction in Plants. — Numerous plants reproduce without flowers, egg-cells, or other structures connected with sexual reproduction. Some of the best-known examples are among the flowering plants. While these naturally reproduce from seeds, which are formed by processes of sexual reproduction in flowers, many of them may reproduce from roots, stems, and even leaves. The following are common examples:

Strawberry plants are commonly obtained from branches (called runners) which creep over the ground and take root at the joints or nodes, and form new plants at these points. In this way one plant has formed more than fifty new plants in a single summer. Black raspberry bushes and grapevines bend over, form roots, and develop new plants where they touch the ground. Red raspberry bushes multiply by forming young plants from underground branches resembling roots. New plants start from roots of osage-orange and some other trees. Some flowering plants may reproduce from leaves; the best example is the "sprout-leaf" or bryophyllum, a garden plant whose leaves fall to the ground,

form roots and shoots at notches on the edges of the leaves, and thus each leaf may form a number of new plants. Some begonia leaves will propagate in the same way. Still other flowering plants propagate from bulbs (which are short stems with leaves). This is well illustrated by certain kinds or varieties of onions. The common onions ("seed onions") are grown from seed in one season, or else the seeds are started one year and form small onions ("sets") which are planted the next spring. In this case one seed forms one set, and one set forms one onion bulb, which when mature forms flowers and seeds; hence multiplication can be only by seeds. Some other kinds of onion bulbs behave differently, in that the bulb which is planted divides (asexual reproduction) into a group of little bulbs ("bulbels"). The multiplier or potato onion does this, and garlic is similar. Each of the little bulbels may be planted and will soon grow to full size, and then begin to form more bulbels. Multiplier onions occasionally produce seed, but gardeners commonly use the "bulbels" for planting. A third kind of onions forms "top onions" or "bulblets" on the flower-stalks, sometimes mixed with some flowers. These small bulblets may be planted next season and soon grow to usable size, and if left in the ground they will send up flower-stalks which produce bulblets. The so-called "Egyptian onions" and "tree onions" are top-onions. In the wild garlic some of the flowers are frequently replaced by bulblets. The above ways of growing different varieties of onions illustrate the methods of propagating many bulb-producing plants. Hyacinth, narcissus or daffodil, many lilies, crocus, and tulip are examples of flowering plants which are usually grown from bulbs and rarely from seed.

Without the aid of man many flowering plants may propagate asexually from roots, stems, leaves, and bulbs. By man's help many of them which do not naturally propagate

without seeds can be grown from parts of the plants. For example, cuttings or slips may be cut from stems of almost any plant and if properly set in moist soil will form roots and develop into new complete plants. This is the familiar method of starting geraniums, coleus, and other house-plants; and dozens of shrubs (*e.g.*, currant), vines (*e.g.*, grape), and trees (*e.g.*, willow) are commonly started from cuttings of stems.

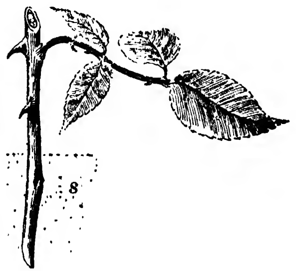

Fig. 101. A rose cutting set in soil (*s*). (*From Cornell Leaflets.*)

Still another artificial method of propagation from cuttings is *grafting* and *budding*. The details of this method are explained in § 301, but essentially it consists in taking a small piece of stem with a bud from one plant and attaching it to root or stem of another plant, on which the transplanted bud grows and forms all the stem above the point where the bud was attached. This is the method for propagating standard varieties of apples, pears, plums, cherries, peaches, and many shrubs and trees.

All such propagation of plants from parts or pieces of full-grown plants without seeds is *asexual reproduction*. In some cultivated plants reproducing by seeds has been supplanted largely by asexual reproduction. This has two advantages: (1) the ease of starting some plants without seeds, and (2) many cultivated varieties will always produce their own variety from parts of themselves, but not from seeds. For example, the seeds from a red apple may produce trees which bear apples that are green-colored and entirely different in flavor, size, etc. The only way to propagate with certainty the desired variety is to take a cutting from a branch

of the apple tree known to bear the kind of fruit wanted and graft it on a tree started from seed. The runners of a strawberry plant will form new plants producing the same quality of berries, but the seeds rarely do so. The tubers (thickened branches of the stem) of potatoes will produce the same varieties, but the seeds do not do so. Moreover, in the case of seedless fruits (*e.g.*, navel oranges and seedless apples) the only possible propagation is by cuttings, buds, or grafts. The millions of seedless orange trees in California have descended from a single tree which grew from seed but could not itself produce seed. Without man's help such a variety could not have multiplied.

REPRODUCTION BY MEANS OF SEEDS

The usual method of reproduction in the flowering plants is by means of seeds which are produced in flowers. Hence, these plants are often called *seed-plants*, the botanical term for which is Spermaphytes. They are designated in some books by the name of phanerogams. In order to understand the parts which flowers and seeds play in the reproduction of this highest group of plants, it is necessary to study some flowers, the fruits which develop from the flowers, and the structure and germination of the seeds in the fruits. For this purpose the bean flowers, pods (fruit), and seeds are excellent.

335. Simple Flowers. — In case any students in the class have not previously learned the parts of any simple flower, they should study one, identifying: (1) The *calyx*, composed of *sepals;* (2) *corolla*, composed of *petals;* (3) *stamens*, composed of the stalk or *filament* and the *anther*, bearing minute grains of *pollen;* (4) in the center of the flowers the *pistil*, composed of the *ovary*, and the *style*, which extends upward and has the *stigma* at its end. Flowers which have separate petals (scillas, tulips, sedum, lilies, etc.) are good for such preliminary study of the parts of simple flowers.

336. Study of Bean Flower. — (*L*) Bean plants six to ten weeks old will furnish all the stages needed for this study. Pea flowers may be used. Either bean or pea flowers may be preserved in one per cent formalin solution.

Note how the *flower-stalks* (pedicels) are attached at the nodes of the stem and often in the *axils* of the leaf; that is, in the angle between leaf and stem. Identify: (1) two green leaf-like structures (*bracts*) at the base of the flower. On very young flower bud on the same plant these bracts may be seen inclosing the flower. (2) Between the bracts and the corolla is the calyx, composed of five sepals united into a cup. This can be seen best in an old flower from which the corolla is ready to fall. (3) The petals (white, pink, or red) of the corolla, five in number and unequal in size, are arranged as in the diagram in Fig. 102. The three largest petals are so prominent that at first sight the flower appears to have only three; but two smaller petals are united and coiled so as to lie between the three largest petals. The largest petal of a flower like that of the bean plant is called the "standard"; the two petals at the sides of the flower are called the "wings"; and the united and twisted petals form the "keel," which lies between the "wings." In a bud just about to open note how the largest petal ("standard") incloses the others.

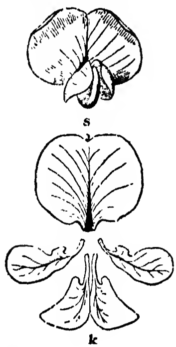

FIG. 102. Pea flower *s*, "standard"; *w*, "wings"; *k*, "keel." (*From Gray.*)

Inside the coil of petals ("keel") are ten stamens and the pistil. Look at a flower in its natural position on a plant and note that the two side petals (the "wings") are the only ones on which a bee could easily alight. If you have opportunity, watch bees visiting bean flowers in the garden. Hold a flower by its stalk in the natural position, and with a pencil press downward on the two side petals, and carefully watch the end of the coiled petals ("keel") as you press. Note how the stigma and part of the style appear when the side petals are pressed, and disappear within the coiled petals when released. Imagine how a bee could cause the same exposure of the pistil when alighting on these petals. Hold these side petals down so as to keep the style protruded and with a hand-lens examine the stigma, and also notice rows of hairs along the style.

Now, carefully uncoil the twisted petals and note how the style and the ten stamens are inclosed by the coiled petals. The filaments of nine of the stamens are joined together at their base. The stamens are firmly fastened in place, but the style is not attached to the spiral tube formed by the twisted petals. The stigma does not touch the anthers, but the hairs just below the stigma brush over the anthers, and some pollen-grains cling to them.

The meaning of the structure of the bean flower is this: When a bee alights on the petals, the stigma and the upper part of the style are exposed and pollen is brushed on the bee's body by the hairs on the style. Then the bee goes to another flower, and when its style touches the bee's body, the stigma will touch some pollen from the first flower; and at the same time the hairs of the style will brush on to the bee some pollen from the second flower. And so, as the bee goes from flower to flower, it will brush pollen-dust on stigmas and get pollen-dust brushed out from the anthers by the hairs on the styles below the stigmas. There is very little chance that the stigma of a flower will get pollen-dust from anthers in the same flower. This may sometimes happen when a bee leaves a flower and at once goes back to it, carrying pollen-dust received on its first visit.

It seems probable from the arrangement of the bean flower that insect visits are necessary to distribute the pollen-dust of this kind of flower. Darwin, the famous English biologist, made many experiments by keeping beans covered with netting so that insects could not reach the flowers, and the result was that seeds rarely formed. Pea flowers are very similar to those of the bean, but the stigma is so near the anthers that it often gets pollen-dust before the flower is visited by insects. Botanists call such a flower *self-pollinated.* The bean, then, is not often self-pollinated, but *cross-pollination* (meaning pollen from other flowers) usually occurs.

Ovules. — (*D* or *L*) Carefully remove the corolla and thus expose the pistil of a bean flower. Hold up to the light and notice a row of opaque spots in the ovary. Then with a sharp knife or a razor split the ovary lengthwise. A low-power microscope or a hand-lens will make clear that the opaque spots are "seeds." In this early stage, however, the term *ovule* should be applied to each one of these structures which later grows into a seed. Inside each ovule an *embryo* develops, and later when the seed sprouts the embryo grows into a new plant.

Pollen-Grains. — (*D* or *L*) Examine some pollen-grains mounted in a drop of water, using first low power and then high power of microscope.

Fertilization. — When pollen-grains have been lodged on the stigma of a flower they soon swell, and each one sends out a delicate tube, which grows down through the tissues of the style and into an ovule in the ovary (Fig. 103). There the *pollen-tube* meets a cell known as the *egg-cell*. Then a mass of protoplasm (really a cell) passes from the end of the pollen-tube into the egg-cell. The union of the two cells is *fertilization*. Soon the fertilized egg-cell divides into many cells, and these form an embryo within the ovule, which grows into a seed.

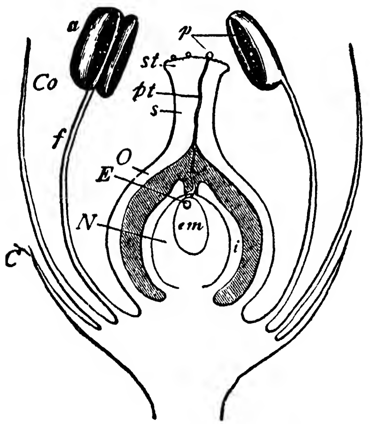

FIG. 103. Diagram of a flower. *C*, calyx; *Co*, corolla; *a*, anther on filament (*f*); *p*, pollen-grains; *st*, stigma; *pt*, pollen-tube; *s*, style; *O*, ovary; *em*, egg-cell in ovule; *E*, fertilizing cell. (*From Bessey.*)

Pea Flower. — (*L*) If material is available, make a brief examination of the flower of a pea, preferably of a sweet pea, in order to see better some parts which are larger than in the bean flowers.

The Bean Pod or Fruit

337. Fruits. — After the stigma of the bean flower has been pollinated by insects, the ovary of the pistil soon begins to develop into the *pod* containing the seeds. Botanists call the pod with its seeds a *fruit*, and apply this name to the structures containing seeds which develop from flowers. Hence many things are known in biology as fruits which we do not popularly call fruits; for instance, a tomato, a bean pod, a squash, or a cucumber is in botany just as much a fruit as an apple, a peach, or an orange.

338. Study of a Bean Pod. — (*L*) On a full-grown bean plant about six weeks old one may usually find pods (fruits) of various sizes, ranging from one slightly larger than the pistil of the flower up to the size of the fully developed pod. The stalk or stem of the pod is the flower-stalk (pedicel), and its expanded end at the point where it is attached to the pod is the receptacle of the flower. In the younger pods, identify the calyx and the bracts of the flower, which can still be seen at the stalk end; and at the other end is the style. Between the calyx and the style is the ovary, which begins to elongate shortly after pollination. If possible, examine the ovary in a faded flower, just about the time that the corolla is ready to fall off. Label sketches of young pods so as to show what parts of the flower develop into the fruit.

Study a full-grown bean pod (use green pods, known as "string-beans"). Sketch and label, naming the parts by comparing with younger pods. The pointed end is the base of the style, most of which, with the stigma, was pulled off by the falling corolla. Note that the pod is composed of two similar valves fastened together along the edges, which are called sutures (meaning seams). The bean pod is *bilaterally symmetrical*. The style and the concave curvature of the pod mark the edge or suture where the seeds are attached. Carefully split open a pod along the opposite edge and note that some beans (seeds) are attached to each half. Is there any regularity as to the number attached to either half? Note that each bean is held in place by a short *seed-stalk* (funiculus). Undeveloped ovules may be seen near the ends of the pod. The

part of the inner lining of the pod to which the seeds are attached is known as the *placenta*.

Break a pod transversely in several places, and notice strong fibers. On which edge of the pod are they? Do you see any relation between the position of the strongest fibers and the natural curvature of the pod? Why are the green pods called "string-beans" by gardeners?

(*D*) Cut a fresh bean branch having young pods, and place cut end in red ink. After a time note where the pods are colored and draw your conclusions as to the functions of the fibers in the pods. Is there any reason why these fibers should be more abundant on one edge of the pod?

(*D*) Note markings on a bean where it was attached to the seed-stalk. The scar left when the seed-stalk is pulled off is called the *hilum*. At one side of the hilum (toward the stalk of the pod) is a small translucent elevation with a slit-like marking. On the opposite side of the hilum is a very minute pit known as the *micropyle*. When pollen-grains touch the stigma, as previously described in § 336, the very small tube that grows from each pollen-grain extends down the style and along the placenta of the ovary to the micropyle of an ovule. Later, when fertilization is completed, each ovule develops into a seed, and the entire ovary into the fruit or bean pod. Make a diagram of a pod with seeds, and show by a broken or colored line the path a pollen-tube must take from the style to an ovule.

The Bean Seed and its Germination

339. Varieties of Beans. — (*L*) Compare color, markings, and size of specimens of some of the common varieties of beans grown in gardens. (The school-museum should have a collection of the most common varieties of beans arranged in small labeled bottles or boxes.)

The variations in color, size, etc., of the seeds are no greater than the variations of all parts of the plants which grow from them: (1) Bean plants may be low (dwarf beans), or climbing (*e.g.*, lima beans); (2) they may have flowers of various colors; (3) the leaves may differ in shape, size, and color;

(4) the pods may be rounded or flattened, short or very long (in one variety two to three feet), green or yellow (so-called "wax beans"), with "strings" (§ 77) or almost "stringless," and with many flavors; (5) some bean plants form edible pods in six or seven weeks after planting (the early and extra-early varieties), while others take a longer time (lima beans are often killed by frost before the seeds are full size). These are a few of the variations of beans which interest gardeners, because all these are qualities sometimes desired. Look over the descriptions of beans in a seed-catalogue, and note the points emphasized in the descriptions of varieties offered for sale.

340. Structure of a Bean. — (*L*) Use any large beans (limas, "yellow six-weeks," "scarlet runner," and "golden-eyed wax" are excellent); some dry, and some which have been soaked in water over night.

Examine the surface markings. Locate the scar (hilum) and the micropyle, which were described in the preceding lesson on the pod. The translucent elevation seen in green beans near the hilum and opposite the micropyle is colored in dry beans of many varieties (dark brown in "yellow six-weeks," light brown in "golden-eyed wax" beans). These conspicuous marks will aid in locating the micropyle on the opposite side of the hilum.

Strip off the *seed-coat* from a water-soaked bean. The seed-coat has two layers, which are easily seen in a green bean. The main body of the bean consists of two thickened halves (seed-leaves or *cotyledons*). These are stored with food for the early use of the young plant that will grow from the seed.

Carefully separate the two cotyledons, and notice a pointed rod-like body which is joined to the cotyledons. This is called *hypocotyl* (Fig. 104, *h*). It is best seen in a bean which has begun to sprout, for the hypocotyl then pushes through the seed-coat at the micropyle. The part of the hypocotyl next the cotyledons will form the beginning of the *stem*, while the pointed end will form the first *root*. Before sprouting begins, it is difficult to see any line between the stem and the root part of a hypocotyl; and we simply call the entire

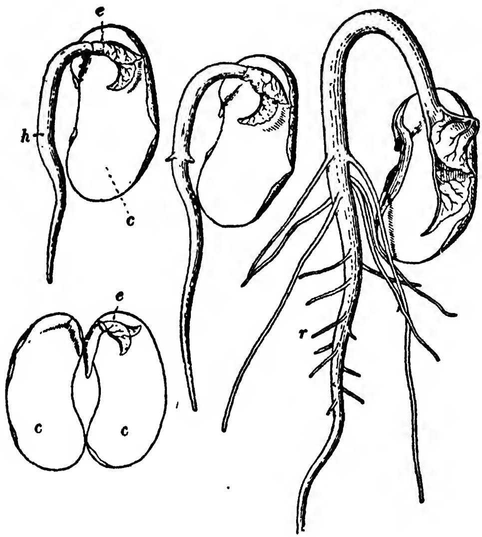

FIG. 104. Bean seed and seedlings. *c*, cotyledons; *e*, epicotyl; *h*, hypocotyl; *r*, roots. (*After Atkinson.*)

structure hypocotyl until growth makes it easy to distinguish between stem and root.

The words caulicle and radicle which are used in some botanical books are practically synonymous with hypocotyl.

Joined to the hypocotyl where this is united with the cotyledons is a very short stem with a pair of small leaves. Between these leaves is a small bud. This short stem with leaves and bud constitutes the *epicotyl.* It will form the stem and leaves above the cotyledons. Some books call the bud with the small leaves a *plumule.*

341. The Bean Embryo. — Cotyledons, hypocotyl, and epicotyl together constitute the embryo which may develop into a bean plant. The part of the plant which develops from each part of the embryo is as follows:

Bean embryo consists of	Cotyledons — not very useful as foliage leaves of bean seedling, but stored with food.
	Hypocotyl — forms stem below cotyledons and root at its lower end.
	Epicotyl — forms stem and leaves above cotyledons.

As we shall see in later studies, the seed-coat is lost as the embryo develops; it is therefore simply a structure for protecting the embryo after the seed is out of the pod and until germination is completed.

342. Germination or Awakening of Seeds. — A dry bean seed shows none of the usual signs of being alive; but it soon revives when placed under proper conditions (with moisture, heat, and oxygen from the air), and rapidly grows into a young plant (called *seedling*, or plantlet). This "awakening" or reviving and growth into a new plant is commonly called *germination;* and the seed is said to germinate. The popular word "sprouting" usually means the early stages of germination.

Germination of Beans. — (*L*) Beginning about two weeks before this exercise, some beans should have been planted every other day in soil (preferably in small boxes or flower-pots which can be taken to the schoolroom). Plant about two inches deep, and keep the soil moist and warm. Plant a few beans four, five, and six inches deep, and some near the soil surface. Mark the position of these with wooden stakes on which figures have been written with lead-pencil. When some young plants (seedlings) are two inches above the soil, and others just emerging, the materials are ready for the following lesson.

Without pulling up any plants, carefully examine and compare the various stages in order to determine where the parts of the embryo seen in the seed are located in the seedling. What becomes of the seed-coat? The first joint or node of the stem is where the cotyledons are attached; the second at the leaves of the epicotyl. Does the internode between these two nodes lengthen? Do the cotyledons of the bean become leaf-like? Compare the size and shape of the leaves of the epicotyl with those you have seen on a large bean plant.

Make a series of sketches showing stages in the emergence of the seedling from the ground. Leave space in note-book for adding other and larger sketches of later stages as the plant develops for several weeks.

In order to find out what happens between the time the seed is planted and the seedling emerges from the soil, we must either dig up seeds planted at various periods of time or we must study these early stages of germination in seeds which are germinated without contact with soil. This latter is best, because the particles of soil cling to the seeds and make them more difficult to study.

To germinate seeds without soil, place them between layers of cotton batting, sphagnum moss, sawdust (some kinds are too acid), blotting-paper, filter-paper, or other soft papers. Keep moist, *not wet*, and warm. Or simply place seeds on a few layers of soft paper on a flat dish (such as a dinner-plate) and keep moist, warm, and covered. Sand or cotton under the paper will help hold moisture.

(*L*) Examine various stages of bean seedlings grown without soil. Compare carefully with seedlings growing with their roots in soil, and make sketches of the chief stages. See Fig. 103.

Conditions of Germination. — It is easy to demonstrate that water, oxygen (from air), and proper temperature are necessary for germination.

Water. — That water is necessary requires no special experimental proof, for every one knows that seeds kept dry remain dormant, and that seedlings do not "come up" in gardens when the soil is dry, as in midsummer. Many hard-coated seeds have special ways of letting in the necessary water, such as the spongy mass at end of castor-bean, and the holes in a coconut. Other seeds must remain in the soil for months until freezing or decay of seed-coats causes cracks into which water can enter. Gardeners often crack certain hard seeds, like peach and various nuts, and they file or cut notches in others. Certain seeds should be soaked and softened in hot water before planting.

Proper Temperature. — Any one who has ever been interested in a garden knows that warm weather is necessary for the germination of most seeds, but that some kinds of seeds will germinate in early spring when the soil is still cold.

By simply placing some seeds on a moist paper in an ice-box and others of the same kind in warmer places one can show the effect of temperature on germination, and after many trials it will be found that there is a best or optimum temperature for each kind of seed. Seed-catalogues and books on gardening usually give the necessary information regarding best temperatures for germinating common vegetable and " flower " seeds.

Air, Oxygen. — That the oxygen of the air is necessary might be expected because a germinating seed is a living plant, and we have learned that all protoplasm must have oxygen. It can be proved by placing seeds in a bottle and pumping out the air with an air-pump, or by filling the bottle with pure nitrogen gas made with a chemist's generator. That carbon dioxide is formed in germinating seeds can be proved by the lime-water test — simply stand a small cup or vial containing lime-water in a larger, carefully stoppered bottle containing germinating seeds. Or use the method described in § 25, suspending seeds in a bag of netting during germination, and then after lifting out the bag, pour lime-water into bottom of the jar.

343. Other Flowers, Fruits, and Seeds. — If time permits, it will be worth while to compare the bean reproductive structures (flowers, fruits, and seeds) with those of other common plants, such as pea, squash, corn, castor bean. Directions for the study of these are given in the authors' " Applied Biology," §§ 135–145, 189–208, 212–217.

Reproduction of Ferns

344. Structure of a Fern Plant. — The stems of the common ferns are either prostrate on the soil surface or underground, but the tropical tree-ferns, often kept in greenhouses, have upright stems. From the horizontal stem of a com-

mon fern the leaves (fronds) grow up each summer, and there are small root-like structures extending from the stem into the surrounding soil. Examine a fern plant and compare its parts with those of a bean or other flowering plant.

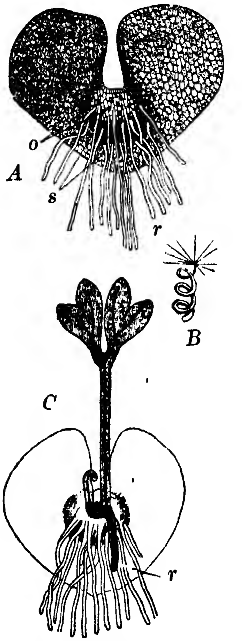

FIG. 105. *A*, fern prothallium developed from a spore which was formed on a fern leaf. *o*, ovaries; *s*, spermaries; *r*, root-hairs. *B*, a sperm-cell from spermary of fern. *C*, a young fern plant growing from a fertilized egg-cell in an ovary on a prothallium. (*After Parker.*)

345. Fern Spores.—Many fern leaves have on their lower surfaces certain elevations, ridges, or folds quite unlike anything found on the leaves of flowering plants. These peculiar structures contain *spore-cases* (sporangia), and these form *spores*.

Spores scattered by the bursting of mature spore-cases absorb water from moist soil, germinate, and grow into a heart-shaped and leaf-like plant, called a *prothallium* (Fig. 105). It may be more than one-eighth inch across its widest part.

346. Sex-Organs of Ferns.—On the under side of a fullgrown prothallium there are ovaries and spermaries.* Each ovary produces an egg-cell or ovum, and each spermary forms many spiral sperm-cells with cilia (Fig. 105). The lashing movements of the cilia cause the sperm-cells to swim in drops of water to the opening of the tube-like ovary

* Spermaries of ferns are often called antheridia, and ovaries archegonia. These names are given here merely for reference to books of botany.

and thence in to meet the egg-cell. One sperm-cell penetrates an egg-cell, and this is *fertilization.*

The *fertilized egg-cell* undergoes repeated division and forms an embryo which soon grows into a young fern plant (Fig. 105). The prothallium withers, the fern plant grows to maturity, produces spores, which germinate and grow into new prothallia. Thus the ordinary fern plant reproduces asexually by dividing off spores, which form the plants known as prothallia, and these reproduce sexually (*i.e.*, by means of egg-cells and sperm-cells) and form new fern plants. The complete life-history includes two generations, the fern plant and the prothallium ; and so ferns are said to have *alternation of generations.* So far as superficial observation goes, the ordinary flowering plants appear to have only one generation, namely, the plants with flowers producing seeds which grow into new plants able to produce seeds. But in advanced courses of botany the student learns that inside the pistil of flowers are microscopic groups of cells which represent the prothallium that lives independently as a stage in the life-history of ferns and other lower plants.

EMBRYOLOGY OF THE FROG

The reproduction of the bean plant has been described as illustrating that of the highest plants (seed-plants), and now we turn to study briefly the development of some of the highest animals (vertebrates). While the fishes are the lowest of this group, it will be more convenient to center our study of vertebrate life-history around the frog, with whose structure and physiology we have become familiar through Chapter VI.

In considering the work of the organs of the frog, we gave attention to those which are necessary for the life of the in-

dividual frog, that is, all organs except the reproductive organs which are necessary only for the continuance of the frog species. The work of the reproductive organs of the frog (as of all other organisms) is the production of new individuals; and to the general facts in this line we shall now give some attention.

347. Egg-Cells and Sperm-Cells. — In the study of the structure of the frog (§ 89), we noted the position and form of the essential reproductive organs (*ovaries* and *spermaries*) and their ducts by which *egg-cells* (from ovaries) and *sperm-cells* (from spermaries) are conducted out of the body into the water in which the animals live. From the ovaries and spermaries of frogs the egg-cells and sperm-cells are discharged in early spring. The eggs develop in the water and hatch as *tadpoles*. Then, after a few weeks or many, depending upon the species, they develop legs, lose their tails by a process of absorption, and become small frogs. This change from tadpoles into frogs is called *metamorphosis*.

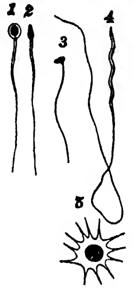

FIG. 106. Various forms of sperm-cells. 1, 2, 3, mammalian; 4, amphibian; 5, crustacean.

The ovaries in a young frog are masses of tissue with numerous small egg-cells. Each egg-cell is a spherical mass of protoplasm with a nucleus near its center. As the eggs grow larger, each one accumulates granules of a material known as *yolk;* and after a time the yolk comes to occupy one hemisphere of the egg, while the protoplasm is concentrated in the other. Frogs' eggs examined soon after they are laid in water are seen to be black (with pigment) in one hemisphere, and whitish (due to yolk) in the other. The black hemisphere contains most of the protoplasm. Each egg is surrounded by an envelope of transparent jelly, which was secreted by the

cells of the oviduct as the egg passed from the ovaries to the exterior.

The sperm-cells have the form shown in Fig. 106. The thickened part is chiefly nucleus. The tails of living sperm-cells vibrate rapidly and enable the cells to swim in the water, into which they are discharged.

348. Fertilization. — Before an egg-cell can develop to form a tadpole it must be entered by a sperm-cell. Soon after the egg-cells of a frog are discharged into the water, they are approached by the swimming sperm-cells and each egg is entered by a sperm-cell. The sperm-cell then becomes

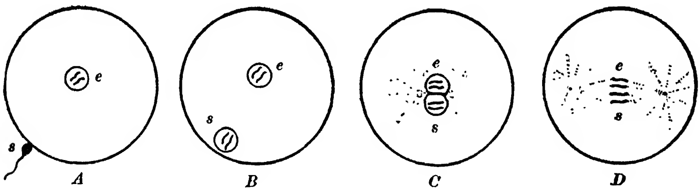

FIG. 107. Diagrams illustrating fertilization of an egg-cell by a sperm-cell. *A*, *e*, nucleus of matured egg-cell; *s*, a sperm-cell ready to enter. *B*, sperm-cell entered and transformed into sperm-nucleus (*s*). *C*, sperm-nucleus and egg-nucleus united, fertilization complete. *D*, division leading to two-cell stage. The nuclei are represented as having only two chromosomes; but those of most sperm- and egg-cells have more.

a second nucleus, called sperm-nucleus. This nucleus approaches that of the egg-cell, and the two nuclei unite. When this has occurred, the egg-cell is said to be *fertilized*, and the entering of a sperm-cell and its union with the nucleus of the egg-cell is called *fertilization* (see Fig. 107).

349. Division of the Egg-Cell. — As soon as the egg-cell is fertilized, it prepares for division into two cells.* In warm spring weather the first division is usually completed within two hours after the egg-cells are laid in the water, and

* For details concerning division, see "Applied Biology," § 59.

the egg is then in the two-cell stage (Fig. 108, F). Each cell appears exactly like the original egg-cell, but is one-half the size. In another hour each cell of the two-cell stage will have gone through the same processes of division, and the four-cell stage will be reached. Such divisions of cells occur about every hour; and so, in succession, stages of two, four, eight, sixteen, and thirty-two cells are formed (Fig. 109). Later, some cells may get slower in division, and hence the stages only approximate 64, 128, 256, and more cells, multiplying by two when all the cells have divided. Usually within two or three days the egg has reached a stage consisting of a spherical mass of many hundred cells; and it is then ready to arrange the cells so as to form the body of a tadpole.

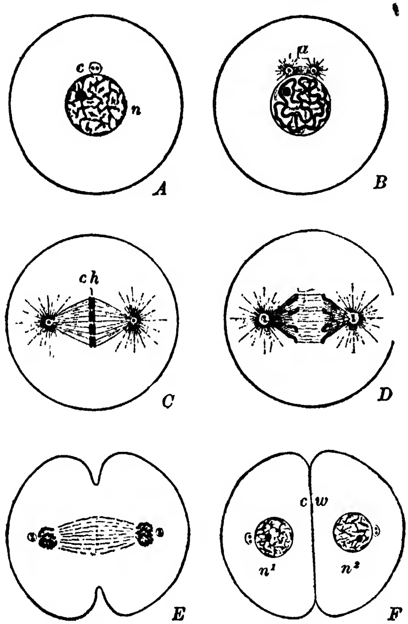

Fig. 108. Diagrams illustrating stages in division of cell (*A*) into two (*F*). *n*, nucleus; *c*, centrosome; *cw*, cell; *ch*, chromosomes. (*From Wilson.*)

350. Later Development. — The changes in external form of developing frogs' eggs should be observed, either in eggs preserved in formalin-solution, or in living eggs (only in early spring) kept in aquaria (*e.g.*, fruit-jars) and examined daily during development. In brief, the changes are as

follows: The spherical mass of cells formed by the numerous divisions of the egg-cell becomes elongated, the various organs are formed by complicated changes which cannot be described in the limited space of this book, and gradually the embryo becomes a tadpole. Finally, the tadpole hatches, that is, it breaks through the jelly that has surrounded the egg throughout the development.

The tadpole at hatching appears larger than a fertilized frog egg; but if dried would not weigh more, for no food

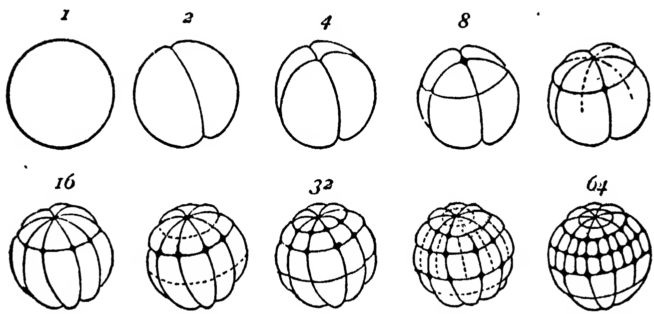

FIG. 109. Stages in division or cleavage of frog's eggs. The figures indicate the number of cells. (*From Thomson, after Ecker.*)

can be taken until after hatching. The larger size of the tadpole, as compared with the egg, is due to water absorbed during development.

The time necessary for a fertilized egg-cell to develop into a free-swimming tadpole varies with the temperature of the water. Also, the eggs of some species develop faster than others; toads' eggs will hatch within three or four days after being laid and those of wood-frogs develop almost as rapidly.

351. Metamorphosis. — The time necessary for a tadpole to become full-grown (Fig. 110) and to metamorphose into

a toad or a frog varies with species, and with food and temperature of water. Toad and wood-frog tadpoles may metamorphose within one or two months after hatching. Such rapid development is important, for these animals often lay their eggs in temporary pools which become dry in late spring or early summer. Bull-frogs and some green frogs may live in the tadpole stage at least a year, for in early spring there are in permanent ponds many large tadpoles showing no signs of developing legs and shortening tails and these are at least one year old. Probably some of these will become frogs in the second summer when somewhat over one year old, while others may live still another year in the tadpole stage.

FIG. 110. Full-grown tadpole dissected on left side. Intestine coiled. *f*, foreleg; *p*, exit from gill-chamber; *l*, left lung. (*From Aus der Natur.*)

The nature of the metamorphosis of a tadpole into a frog is popularly misunderstood. The tadpoles are said to "lose their tails," and this is often taken to mean that the tails drop off. This is not true. In collecting tadpoles in ponds one often finds specimens with short stubby tails and well-developed legs, and others showing various intermediate stages between these and tadpoles with long tails and no legs. The explanation of these different conditions is that after the legs develop the tail is absorbed. First, the tissues inside the end of the tail are disintegrated by the white blood-cells, which "eat" the particles of tissue and carry them back into the body. In a short time after this process starts, the tip of the tail appears withered. The white blood-cells continue this process of disintegration and removal of tissues until the tail has entirely disappeared.

Thus instead of the tail dropping off, as is commonly believed, its substance is gradually carried back into the body by internal processes of absorption, and the materials are used in building other tissues.

FIG. 111. Transformation of tree-frog tadpole in 24 hours. Natural size. (*From Cornell Leaflets.*)

352. Embryonic and Larval Development.— The development of any fertilized egg to the hatching stage is called *embryonic development;* and the scientific study of such stages of the frog and other animals is *animal embryology.* The tadpole is often called a *larva,* and its changes constitute *larval development.*

All species of backboned animals have embryonic development; but a large number do not have a larva, for their eggs develop directly into miniature animals resembling the adults. For example, it is well known that birds are hatched as small birds, and common mammals at birth show the characteristics of their species. All young animals which at hatching are quite unlike their parents (*e.g.*, as tadpoles are unlike frogs, and caterpillars are unlike butterflies) are said to have a larval development.

353. Oviparous and Viviparous Development. — All such animals as frogs, birds, turtles, fishes, etc., which lay eggs that develop outside the body of the animal that produced

them, are called *oviparous*. Such eggs are usually protected by special coverings or shells. We shall see later that such oviparous development is very common in the animal kingdom.

In many species of animals, eggs are retained in the oviducts or other specialized cavities until embryonic development is completed, and the young animals are " born alive "; by which we mean that as organisms ready for an independent existence they are expelled from the cavity in which embryonic development occurred. Such internal development is *viviparous*. It occurs in all mammals, except the duck-bills of Australia; in some snakes; in some salamanders; in some fishes; in some insects; and in other kinds of lower animals.

There is a great advantage in viviparous over oviparous development in the protection afforded the eggs and embryos. Hence relatively few eggs need be produced. It is well known that many fishes and other oviparous animals produce an astounding number of eggs, and that vast numbers of the eggs and young are destroyed. Sharks illustrate the advantage of viviparous development for fishes. Few eggs are formed, and these are retained in the oviducts, not only until the young animals are fully formed, but for many months, until they have grown to be several inches long. They are then born (expelled by muscular contraction of these oviducts), and are well able to shift for themselves. Thus a few sharks' eggs well protected during development will perpetuate the species as successfully as would hundreds of eggs forced to develop oviparously and exposed to attacks of numerous enemies.

A similar case is found among salamanders, which are near relatives of the frogs and toads. Our common salamanders lay each spring large masses of eggs. In a species which

lives in the mountains in Europe, each female forms but two eggs in a year, and these are retained in the oviducts until developed into young salamanders ready to care for themselves.

354. Reproduction of Fishes. — In all species of vertebrates there are both male and female individuals; and new individuals always originate from egg-cells fertilized by sperm-cells.

The eggs of most fishes are laid ("spawned") in shallow water in quiet places, and sperm-cells discharged into the water fertilize the eggs. The enormous loss of eggs and young fishes under natural conditions has led to artificial fish-culture under the control of various states and the United States Bureau of Fisheries. The methods of hatching are a scientific application of nature's way. Fishes are caught by nets at the breeding season, and pressure on their ventral surfaces causes extrusion of eggs and sperm-cells. These

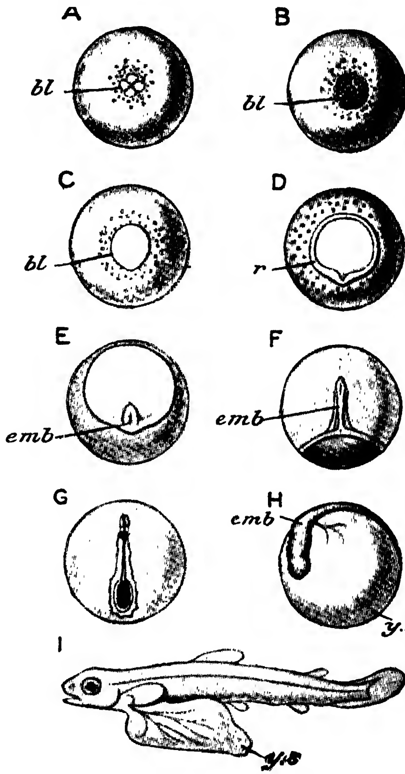

FIG. 112. Stages in development of a fish. *bl*, germ-disk, remainder of the egg is yolk; *emb*, developing embryo; *ys*, yolk-sac. (*From Parker and Haswell.*)

are mixed in water and allowed to stand in shallow pans or water-tight boxes until the sperm-cells have by swimming reached and penetrated the egg-cells (one sperm for each egg), and fertilized them. Later, the fertilized eggs are placed in boxes arranged so that water runs over them while they develop. After hatching, the young fish (called fry) are kept in small pools or tanks, where they are easily fed and protected until large enough to care for themselves in rivers and ponds where their enemies live. Of course many are killed after they are turned loose, but artificial hatching is advantageous in that the developing eggs are protected.

The spawning habits of some fishes are most remarkable. Some salmon ascend the Columbia River from the sea for more than a thousand miles, at an average rate of 3 to 4 miles a day. After depositing eggs and sperm-cells, they all die; and no old fish lives to lead the young ones downstream to the sea. This single spawning occurs after the salmon are at least three years old. It is not true, as sometimes stated, that they *always* go back to the river where they were hatched; but they probably do not go far from the mouth of the river, and hence are likely to ascend the same river when fully developed and ready to spawn.

The shad of our Atlantic Coast is another example of a fish that ascends rivers to spawn; but this fish lives to return to the sea after spawning. More than 200 million shad eggs are artificially hatched each year.

The common river eels migrate downstream in the autumn to spawn in the sea, and after spawning in deep water, the old eels die. Hence adult eels never migrate upstream. In spring, vast numbers of young eels, about one year old, appear below dams and waterfalls. A female 32 inches long may have more than ten million eggs. The life-history of eels was a complete riddle until about twenty years ago, when it was found that the eggs are laid in deep sea-water.

Codfish spawn near the shores of New England between December and April. The hatcheries liberate annually more than 75,000,000 young fry. It is easy to collect the cod eggs for hatching, for in a 20-pound female the two ovaries (popularly called "roes") contain more than 2,500,000 eggs, which are so small that a quart bottle will hold about 335,000. Think of how abundant codfishes would be if all the eggs of a thousand females were to hatch and grow to maturity, and one-half of these were to be equally prolific females. However, since cods do not appear to be either increasing or decreasing rapidly, we are justified in concluding that, on the average, two eggs from each female produce mature individuals. The others are destroyed by enemies or die from diseases. This is a good illustration of the intensity of the struggle for existence, which, to a great extent, affects all animals and plants.

355. Reproduction of Higher Vertebrates. — The early stages of the embryonic development of reptiles, birds, and mammals have a general similarity to those of the frog (§ 59). In all cases, the fertilized egg-cell divides into numerous cells which then form the body of the embryo.

It is a significant fact that there is great similarity in the early stages of all vertebrates. This is illustrated by Fig. 113, in which in parallel columns are early, intermediate, and late embryos of a fish, a salamander, a reptile, a bird, and a mammal. In the early stages there is so great similarity that only specialists in zoölogy could distinguish between these embryos; but as development proceeds there is more and more differentiation, and the final stages at birth and hatching are easily identified as fish, bird, etc.*

* To Teachers: If class time allows, describe the gill-slits as the most remarkable of similar structures in vertebrate embryos. See "Applied Biology," § 364.

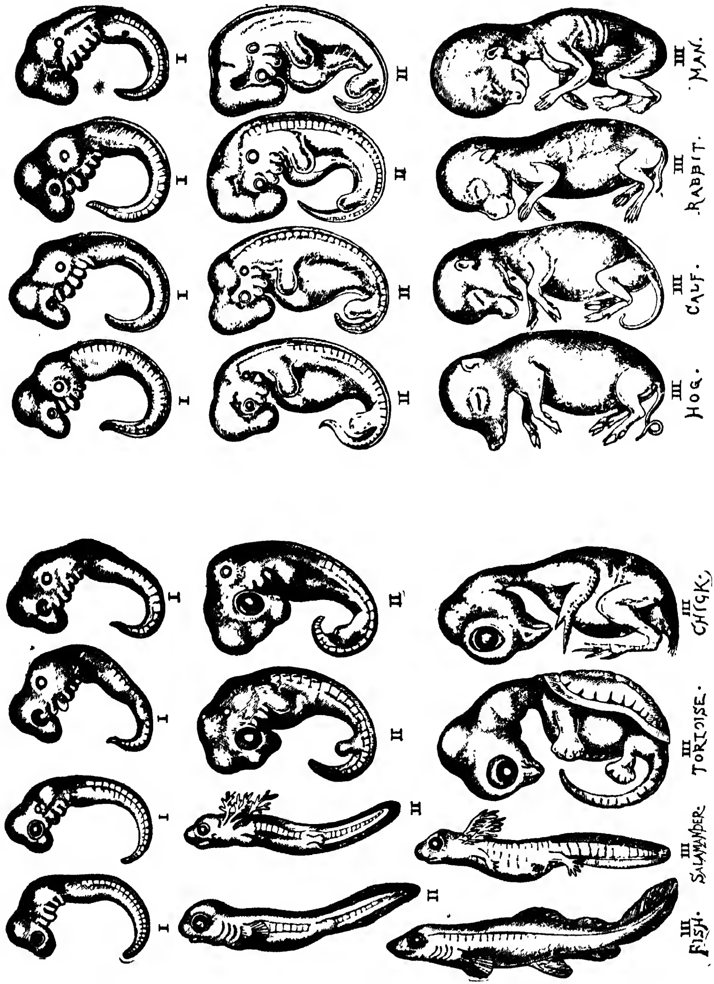

FIG. 113. Similarity of early stages of vertebrate embryos (in column I) and differentiation before birth or hatching (column III). (*From Romanes, after Haeckel.*)

356. Bird Development. — All species of birds are *oviparous* (external development); and the eggs require *incubation.* For this a certain temperature is essential (about 40° C. or 104° F. for hen's eggs). The eggs are fertilized soon after they leave the ovary and enter the oviduct, and cell-division goes on for about a day while the eggs are passing through the duct to the exterior. But soon after an egg is "laid" it becomes cooled to below the normal temperature and development stops. Within a variable number of days, the development may start again, if the egg be warmed to the proper temperature. In natural conditions this is provided for by the instinct which causes female birds (sometimes the male) to sit on or brood the eggs. The feathers prevent rapid loss of the heat afforded by the warm ventral surface of the body of a brooding bird. This brooding instinct usually appears soon after a female bird has laid the eggs which in a given season have developed in the ovary. In many wild birds such a season of egg-laying comes only once a year; in some species two or three broods of eggs may be laid in a summer; and the well-fed domesticated hen may lay from 100 to more than 200 eggs per year, if not allowed to waste time and energy by brooding after each set of 10 to 20 eggs, as they instinctively do. The eggs of birds are large because they have a great store of food (yellow "yolk," and the "white" or albumen) for nourishment of the embryo during the development. The eggs in the ovaries of young birds are small

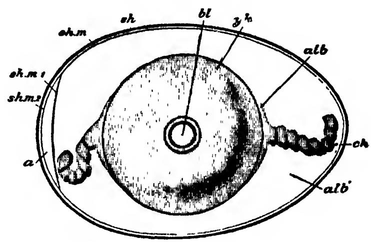

Fig. 114. Diagram of bird's egg. *yk*, yolk; *abl*, white or albumen; *bl*, germ-disk; *ch*, thickened albumen, which holds yolk in position; *sh.m*, two shell membranes. (*From Parker and Haswell.*)

spherical cells, but as they mature the storage of food causes enlargement. For example, in an ordinary hen's egg the "yolk" with its inclosing yolk-membrane is about one inch in diameter, but in a young ovary it is a microscopic cell. The "white" or albumen which surrounds the yolk and also the shell are secreted around the egg as it passes through the oviduct on the way to the exterior. Obviously, the "yolk" is the real egg, corresponding to a frog's egg, and the "white" and shell are later additions formed like the jelly around frog's eggs.

Careful observation of the "yolk" of a bird's egg will disclose a white spot on its upper surface. To see this, place a fresh egg on some cotton or sawdust, carefully chip the shell with forceps, or cut with scissors, making a hole about one inch in diameter. The white spot on the "yolk" is the *germ-disk* from which the embryo will develop; and all the other material inside the yolk-membrane is food. Hen's eggs kept under sitting-hens, or in incubators, for 15, 24, 36, 48, and 72 hours, and then opened (as directed above) will show a series of stages in the growth of the embryo in the germ-disk.

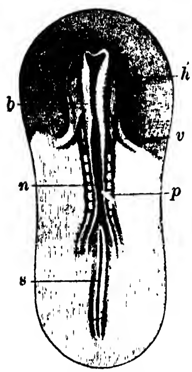

FIG. 115. A chick embryo of one day's incubation. *b*, beginning of brain; *h*, head; *v*, vein to yolk; *n*, neural grove (later spinal cord); *p*, protovertebræ; *s*, primitive streak. (*From Marshall.*)

Eggs which have been incubated for several days show the embryo surrounded by membranes in part of which there are blood-capillaries). The blood in these is pumped by the embryo's heart, which begins to beat on the second day of incubation. The purpose of circulating blood in the blood-vessels of membranes outside the embryo's body is (1) obtaining food from the yolk and later from the

"white," (2) obtaining oxygen from air which filters in through the pores of the shell, and (3) the discharge of carbon dioxide made by the developing embryo. The importance of the two later processes, which considered together constitute the *respiration of the egg*, is shown by the fact that the embryo dies from asphyxiation (lack of oxygen and excess of carbon dioxide) if the pores of the shell become filled, as when coated with albumen from another egg accidentally broken. Hence, poultry keepers must take great care to keep eggs intended for hatching clean before and during incubation.

The time for incubation varies. Hens' eggs hatch in three weeks, ducks' eggs in four weeks, and other birds have either shorter or longer incubation. No one knows why the egg of one species of bird requires more time than does that of another.

357. Reptile Development. — Some snakes, the alligators, and all turtles are oviparous, and their embryos are like those of birds. Incubation is due to the sun's heat and not to brooding by parents. Some snakes and lizards are viviparous, the eggs being retained in the oviducts until fully developed into young animals which are then ejected by muscular contraction of the oviducts. The eggs of these viviparous reptiles are similar to the oviparous ones, and contain much stored food (yolk) to be used by the developing embryos. Among viviparous snakes the garter-snake sometimes gives birth to as many as forty-five in one brood; the rattlesnakes produce 9 to 14; the copperhead, 7 to 9; and the water-moccasin, 7 to 14.

358. Mammalian Development. — We have already (in § 353) noted the advantages of internal or viviparous development over the external or oviparous method; and that while cases of internal development occur among animals of many groups, it is in the mammals that we find vivipary universal,

with the one exception of the Australian duck-bill or duck-mole, which lays eggs.

In adaptation to viviparous development part of the oviducts of the mammals are expanded and fitted for holding eggs during their embryonic development. Such an expanded part of an oviduct adapted for developing embryos is called a *uterus* or womb. In some low mammals, like kangaroos and opossums, there is a right and a left uterus formed by expansion of part of each oviduct. These lie in the same position as the oviducts of frogs. In higher mammals the right and left uteri grow together during embryonic life, and so there is a single uterus with a tube (Fallopian) extending to each ovary (right and left). Egg-cells formed and discharged by either right or left ovary pass through the corresponding tube into the uterus and there develop into embryos.

In all mammals the egg-cells discharged are fertilized near the ovaries in the Fallopian tubes by sperm-cells which have arrived there by swimming through the secretions on the living membranes of the uterus and tubes. The fertilized egg begins to divide at once and may have undergone considerable development when, after a few days, it slips from the tube into the uterus.

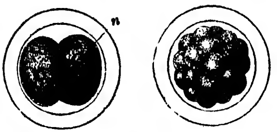

Fig. 116. Rabbit egg in two- and many-cell stages. *n*, nucleus.

The number of egg-cells fertilized at one time varies in different species. It is well known that many domesticated animals (*e.g.*, sheep, cow, horse) usually have one offspring at a time; but some occasionally produce two (twins) or even three (triplets). Others commonly produce many young at a time (*e.g.*, dog, cat, pig, rabbit, mice). The number of young produced indicates the number of egg-cells which were matured and fertilized.

The period of development in the uterus from fertilization to birth of the young is commonly known as *gestation* or *pregnancy;* and the length of time is highly variable. It is approximately 21 days in guinea-pig, 30 days in rabbit and squirrel, 55 days in cat, 62 days in dog, 3 months in lion, 4 months in pig, 5 months in sheep and goat, 6 months in bear, 9 months in cow, over 9 months (280 days) in human species, 10 months in whale, 11 months in horse, 14 months in giraffe, and 22 months in elephant. These are simply illustrations selected from familiar mammals.

In order to provide for the nutrition and respiration of embryo mammals, a complicated connection is made between the blood-system of the embryo and that of the mother. Figure 117 shows a rabbit embryo with its surrounding membranes. These are abundantly supplied with blood-vessels connected with the embryo's heart. Figure 118 shows the position of an embryo mammal in a uterus. The darkly shaded area around the embryo represents lining tissue (epithelium) of the uterus, and this tissue receives its blood-supply from the heart and arteries of the mother. The tree-like processes shown in Fig. 118 are further outgrowths of the irregular processes shown in black on the outer membranes of the embryo rep-

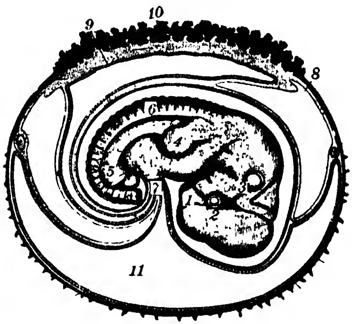

FIG. 117. Rabbit embryo of twelve days' development, with its surrounding membranes which serve for attachment to the lining of the uterus. 1, nose; 2, eye; 3, ear, 4, fore-leg; 5, hind-leg; 6, backbone; 7, umbilical cord; 8, amnion (protective membrane); 9, allantois (absorber of food and oxygen); 10, tree-like processes that unite with the uterus; 11, sac filled with fluid (*From Marshall.*)

resented in Fig. 117. These tree-like processes receive their blood-supply from the embryo's heart through blood-vessels in the umbilical cord attached to the embryo at the umbilicus or navel. As a result of this close attachment of the membranes of the embryo and the lining of the uterus, the blood-vessels of the two are near enough to allow osmosis. From the maternal blood-capillaries foods and oxygen osmose into those of the embryo, and excretions of the embryo's cells pass into the maternal blood. Solid bodies, like red blood-cells, cannot pass from the maternal to the embryo's blood; and the blood-cells in the embryonic blood-vessels are formed from certain cells belonging to the embryo. However, the important point is that food, oxygen, and excretions osmose between the maternal and embryonic blood-vessels in the membranes which attach the embryo to the wall of the uterus.

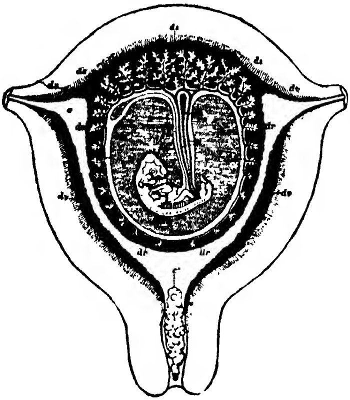

FIG. 118. Diagram of a mammalian uterus, showing attachment of an embryo to the lining (black in the figure). The umbilical cord, from the ventral surface of the embryo's abdomen, extends to the tree-like processes imbedded in the lining of the uterus. The black lines in the umbilical cord indicate arteries and veins connected with the embryo's heart. The openings of the uterus shown at upper right and left are the Fallopian tubes leading to the ovaries, while the lower opening is the mouth of the uterus through which the mature embryo is finally expelled by muscular contraction. (*From Marshall.*)

The membranes which attach the embryo to the uterus constitute the *placenta*. It normally separates from the uterus after the birth of an embryo, and is then itself discharged by muscular contractions of the uterus.

The fact that an embryo attaches to the wall of the uterus as above described and is thus enabled to get food from the blood circulating in the tissues of the mother explains the large size of many mammals at birth. The eggs of all mammals are transparent cells of microscopic size at the beginning of development.

It should be noted that the entire time of gestation is not occupied with the formation of the embryo's organs. For example, an embryo may develop in two or three months so that it has the form and structure of an adult, but may be held in the uterus many more months in order to afford protection and nourishment while it grows larger and stronger. This later stage after the organs are formed is often called a *fœtus*, so as to reserve the word *embryo* for the early stages when the organs are developing.

In the limited time available in this course we cannot do more than study the mere outlines of mammalian development as stated in the foregoing. There are many facts in this line which are especially interesting because of the light which they throw on human life, and for these the reader must be referred to special books, and to college courses in embryology of animals.

All the general statements made above concerning mammalian development apply to human development. The great similarity of the embryos is shown in Fig. 113.

HEREDITY AND EUGENICS

359. Offspring like Parents. — An account of the reproduction of organisms would be incomplete without some reference to heredity. It is a well-known fact that offspring tend to resemble their parents closely. We commonly speak of characteristics which previously appeared in the parents or even earlier progenitors as inherited or due to heredity.

What may be Inherited. — It is a popular saying that "like tends to produce like." This means that each animal and plant has the power of transmitting its own general characteristics to its offspring, *e.g.*, a frog transmits frog characteristics, a bird those of its own species, and so on. Such characteristics which are part of the constitution of organisms are often called *germinal*, which means in the ova and sperm-cells.

Characteristics developed during the lifetime of any individual, dating from the fertilized egg, are said to be *acquired.* Any change in structure due to use or accident, *e.g.*, development of muscles by exercise, or loss of organs by accidents or surgical operations, produces an acquired characteristic.

Stating briefly the essential facts of heredity as now known, characteristics acquired during the lifetime of individuals are not transmitted in heredity, while germinal ones are capable of inheritance. For example, the horns have been removed from many cattle, the appendix from many human individuals, tails from sheep and certain breeds of dogs; and in no case has the removal of any organ from a parent caused the birth of offspring without the organ. In short, such acquired characteristics are not inherited. On the other hand, a cow which was germinally hornless (*i.e.*, born without ability to grow horns) would probably transmit the tendency towards absence of horns to a considerable percentage of her offspring, and these, in turn, would tend to produce hornless offspring. In fact, the breeds of hornless cattle, which are now becoming popular among farmers, have been developed by selecting for breeding certain individuals born without the beginnings of horns. Likewise, dogs and cats born with short tails are likely to transmit that germinal characteristic, which in some unknown way is carried in the reproductive cells from parent to offspring.

The above paragraph states the facts verified by careful observation in hundreds of cases. In fact, the numerous varieties of domesticated animals and plants have originated by man's selection of individuals which during their embryonic history began to develop peculiarities. If these peculiarities make the individual decidedly different from its parents, a new breed might be originated, as from the first hornless cow from horned ancestors. Usually, however, the peculiarities are little things which, if selected by man, will make an improvement in the breed. Hence the scientific farmer is continually watching for young animals which show some slight improvement over their parents; and he goes through his fields in search of corn and other plants which are better than the others. This, in brief, is the secret of the remarkable improvement in almost all kinds of farm animals and cultivated plants in the past fifty or one hundred years.

360. Inheritance from Both Parents. — It is obvious that in cases of asexual reproduction of organisms (§§ 331–333) and of the development of certain insects and plants from unfertilized eggs, there is but one parent from which to inherit. This is one explanation of why plants propagated from cuttings and grafts remain true to their variety, that is, the young plant has the characteristics of its one parent.

All animals and plants developed from fertilized eggs inherit equally from both parents. Here are a few well-known examples: If the pistils of flowers of a tall pea plant be artificially pollinated with pollen from a flower on a dwarf variety of peas, the resulting hybrid seeds will produce tall plants. This appears to be inheritance from the tall parent only, but the dwarf characteristic is merely hidden. The hybrid tall plants, pollinated from their own flowers, will produce seeds of which 25 per cent will form dwarf plants, 25 per cent pure tall plants, and 50 per cent that in later generations will give

equal proportions of dwarf and tall. This proves that there was equal inheritance from both the dwarf and tall parents used in making the hybrid peas.

If black female cavies ("guinea-pigs") be mated with white males their hybrid offspring will be dark colored as shown in Fig. 119, *C*. Now, if these hybrid offspring are paired, their offspring will average 25 per cent pure white, 25 pure black, and 50 that are black, but really mixed because they are able to produce equal numbers of white and black. Thus it appears that the hybrids shown in Fig. 119, *C* inherited colors from both parents shown in *A* and *B*, but the white is concealed in the first generation. Specialists on heredity call the obvious black dominant and the hidden white is recessive.

Another interesting proof that there is inheritance from both parents is the fact that a long-haired white male cavy and a short-haired black female will produce long-haired black offspring, the color from the mother and the long hair from the father.

Facts such as those stated above for peas and cavies are now known in many cases where it is possible to get hybrids between parents which are markedly unlike, such as the difference of color of the cavies or of height of the peas. The peculiarities of one parent are often so dominant that the hybrids appear to inherit from only that parent; but later generations, or even other structures like the long hairs of the white cavy, show that the other parent was equally represented.

Such cases as those of peas and cavies, in which the characteristics of each of the two parents that form hybrids become segregated in 25 per cent of the offspring of each succeeding generation are examples of *Mendelism*. This principle of heredity was discovered by Mendel, an Austrian

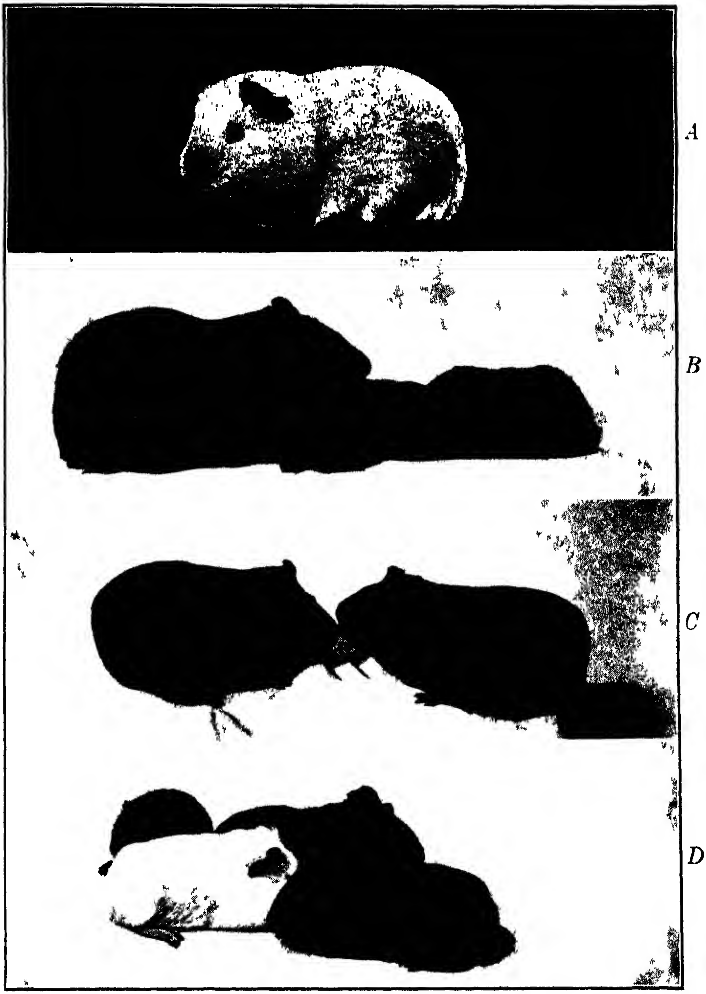

FIG 119 *A*, white male cavy, *B* black female and three black offspring by black male, *C*, two hybrid offspring of the white male and black female shown in *B* and black dominant, *D*, offspring of such hybrids as in *C* one in four are white and three black Two of the three black will produce one white to three black offspring but one is pure black (*From Castle's "Heredity,"* *Appletons*)

monk, who for many years cultivated and hybridized peas in his garden and published his results in 1865.

Since an offspring inherits from each parent, it follows that the egg-cell and the sperm-cell which unite to produce the new individual are the bearers of heredity. But how these simple cells can determine that the new individual into which they develop shall resemble its parents is entirely a mystery to biologists.

361. Eugenics. — There are many other principles of heredity which concern inheritance from parents. Many of them are applicable to human life, and within recent years there has been great popular interest in *eugenics*, which means the application of the known laws of heredity in order to produce more perfect human individuals. At present most of the writers on eugenics are urging that abnormal humans, such as the deformed, the weak-minded, the insane, and the physically weak, should not become parents because the chances are that a considerable number (but not all) of their descendants within a few generations will inherit the unfortunate characteristics. All this applies only to characteristics that are inborn or congenital, for, as explained in § 359, changes which occur after birth could not be transmitted to offspring. Of course, insanity and idiocy may not show at birth, but there may be an inherited weakness of nervous organs which sometimes leads to insanity in the adult, and such weakness may be transmitted in heredity.

362. Spontaneous Generation. — It is now the commonly accepted idea that living things develop only from similar living things. However, this idea that all life comes from life is rather recent. In former times, even scientific men believed in *spontaneous generation* of life in dead, or not-living matter. The sudden appearance of numerous earthworms,

frogs, mice, insects, etc., was explained by assuming that they had suddenly originated spontaneously. When accurate studies of life-histories began to be made, it soon became evident that all the larger animals and plants originate only from organisms like themselves. Until 1638 it was supposed that maggots developed spontaneously from putrid meat; but in that year an investigator showed that maggots never appear on meat which is screened so as to keep flies from laying eggs on it. In some country regions it is still believed that horsehair worms, which are often seen in stagnant pools, have developed from horsehairs, which they superficially resemble. But that there is no connection between the worms and the hairs can be demonstrated by any one who will place in bottles, stoppered with cotton, one or a thousand horsehairs, and await development. Scientific men long ago studied the structure and embryology of horsehair worms and solved the mystery of their appearance in pools, watering troughs, etc. The structure of the worm is essentially the same as that of the other round worms. Its scientific name is Gordius, in allusion to its habit of twisting into a tangle like the famous Gordian knót which Alexander the Great cut with his sword. Its eggs develop into minute larvæ, which become parasites in insects, fishes, frogs, and other animals. Later, the parasites escape from these animals and develop into horsehair worms. Those seen in horse-troughs have completed their life-history in insects. Studies of habits have shown that the sudden appearance of earthworms is caused by flooding of their burrows, and that they do not rain down; and that crowds of toads, frogs, mice, grasshoppers, etc., are due to very favorable conditions for developing eggs and to migrations into new territory. All other such cases which puzzled even the scientific people of a few hundred years ago have been ex-

plained so well that for more than a hundred years no scientific man has believed in the existence of spontaneous generation of any organisms higher than the bacteria. But until the studies by Pasteur, supported by the work of the English physicist Tyndall, between 1850 and 1870, it was believed, even by men of science, that certain bacteria may develop spontaneously in sterile bouillon and other foods. Pasteur showed that if proper precautions are taken to make the foods perfectly sterile, that is, to kill all life in the test-tubes used, and to prevent entrance of other germs, no organisms will develop. In short, Pasteur showed that there is no evidence that living matter originates spontaneously from not-living matter. He did not show that it could not happen, for there may be conditions of which we know nothing, as perhaps existed at the first appearance of living matter on the earth; but he showed that the few cases in which some scientific men of his time still believed had not been sufficiently tested by accurate experiments. So far as concerns the origin of new individuals of all known species of organisms now existing, we may summarize the studies which culminated with those of Pasteur in the statement that all living things come from living things, or *all life from life.*

APPENDIX

Table for Reference to the "Applied Biology" and the "Teachers' Manual of Biology"

Note. — In the first column of figures, in italics, are the section numbers of the "Introduction to Biology," and in the second column, in Roman type, are the numbers of the sections of the "Applied Biology" and the "Teachers' Manual" in which the same topics are presented and from which, in many cases, the teacher can get additional subject-matter and suggestions for practical work. Where "000" appear in the second column there are no special references to the "Applied Biology."

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